Brady Creek
Watershed Protection Plan

Prepared for:

U. S. Environmental Protection Agency

Texas Commission On Environmental Quality

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August 24, 2016

Funding for the development of this watershed protection plan was provided through a federal Clean Water Act 319 (h) grant to the Upper Colorado River Authority (UCRA). The grant was provided by the U.S. Environmental Protection Agency (EPA) and administered by the Texas Commission on Environmental Quality (TCEQ).

ABBREVIATIONS AND ACRONYMS

ac-ft	Acre Feet
AU	Assessment Unit
BMP	Best Management Practice
BOD_5	Biochemical Oxygen Demand (5-day)
CBOD	Carbonaceous Biochemical Oxygen Demand
cfs	Cubic feet per second
cms	Cubic meters per second
CWA	Clean Water Act
CWQMN	Continuous Water Quality Monitoring Network
CHLA	Chlorophyll-α
DO	Dissolved Oxygen
ECHO	Enforcement & Compliance History Online
EMC	Event Mean Concentration
FDC	Flow Duration Curve
HUC	Hydrologic Unit Code
kg	Kilogram
km	Kilometer
LCRA	Lower Colorado River Authority
µg/L	Micrograms/liter
MGD	Million Gallons Per Day
mg/L	Milligrams/liter
mL	Milliliter
NCDC	National Climatic Data Center
NH_3-N	Ammonia as Nitrogen
NLCD	National Land Cover Database
NO_3-N	Nitrate as Nitrogen
NO_{23}-N	Nitrite-Nitrate as Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
Organic-N	Organic Nitrogen
Organic-P	Organic Phosphorus
PO_4-P	Orthophosphate as Phosphorus
QUAL2E	EPA sponsored one-dimensional water quality model
QUALTX	TCEQ one-dimensional water quality model
RKM	River Kilometer
RR	Ranch Road
SOD	Sediment Oxygen Demand
sq. mi.	Square Mile
SSURGO	Soil Survey Geographic
SWAT	Soil & Water Assessment Tool
SWMM	Storm Water Management Model
SWQMIS	Surface Water Quality Monitoring Information System

SWQS	Surface Water Quality Standards
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TIAER	Texas Institute for Applied Environmental Research
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TPDES	Texas Pollutant Discharge Elimination System
TSS	Total Suspended Solids
TSSWCB	Texas State Soil & Water Conservation Board
UCRA	Upper Colorado River Authority
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
VBA	Visual Basic for Application
WPP	Watershed Protection Plan
WWTF	Wastewater Treatment Facility

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1.0 EXECUTIVE SUMMARY

The Brady Creek watershed lies within the larger Colorado River basin. The headwaters of Brady Creek originate in western Concho County, thence flows east through Concho and McCulloch Counties to its confluence with the San Saba River in San Saba County. The Brady Creek watershed consists of 18 HUC 12 watersheds and encompasses an area of approximately 513,000 acres. It is a tributary of the San Saba River. The 18 HUC 12 identifiers geographically distributed from upstream to downstream are as follows: 120901100101 through 120901100108 upstream of Brady Lake and 120901100201 through 120901100210 downstream of Brady Lake.

Water quality in Brady Creek through the City of Brady has continued to degrade since the construction of Brady Lake. Brady Creek has been identified as impaired on the Texas 303(d) list since 2004 for not supporting its designated aquatic life due to low dissolved oxygen (DO). The absence of scouring stream flows and perennial flows has resulted in the stream functioning primarily as a series of storm water ponds with intermittent stream flows. As a result, it often displays the characteristics of a eutrophic stream with prolific algae blooms, odors, and a generally unpleasant appearance.

As a result, in partnership with the City of Brady and the Lower Colorado River Authority (LCRA), the Upper Colorado River Authority (UCRA) applied for and received funding for two (2) Nonpoint source (NPS) abatement projects (Phase I & II). Phase I included the completion of a Master Plan for the downtown portion of Brady Creek and an evaluation of potential Best Management Practices (BMPs). Phase II included demonstration BMPs and a preliminary Watershed Characterization Plan, based primarily on developing a Watershed Protection Plan (WPP) for the entire Brady Creek watershed.

Under the present NPS project, UCRA is has led stakeholder efforts to develop a WPP for the Brady Creek watershed. The primary goal of the WPP is to restore water quality to meet stream standards in Urban Brady Creek. This completed Brady Creek WPP gives basin stakeholders a strategy that will result in the maintenance and restoration of water quality conditions consistent with the State of Texas Surface Water Quality Standards for the designated uses of Brady Creek.

Basin-wide water quality goals include the maintenance of appropriate levels of dissolved oxygen, prevention of eutrophic conditions due to elevated nutrient loads, prevention of erosion and sediment deposition within the stream and, where possible, maximize stream baseflows to restore or enhance aquatic utilization.

In order to determine pollutant loads from unimpaired portions of the watershed, to determine more precise pollutant loadings from the impaired urban watershed within the City of Brady, and to evaluate depressed dissolved oxygen along Brady Creek within the City of Brady, the Texas Institute for Applied Environmental Research (TIAER), as a subcontractor to UCRA, developed and applied appropriate computer models. The Soil and Water Assessment Tool (SWAT), the Storm Water Management Model (SWMM), the QUAL2K model, and Water Rights Analysis Package (WRAP) modeling system were applied to various stream reaches of the Brady Creek Watershed.

The QUAL2K model was used to evaluate depressed dissolved oxygen in Brady Creek within the City of Brady. This modeling effort provided results to assist in evaluating the benefits of re-circulating flow and/or pumping wastewater treatment facility (WWTF) effluent above the area of depressed DO to increase flow in that portion of Brady Creek. The QUAL2K model was also applied to estimate water quality benefits to the urban portion of Brady Creek from reductions in urban pollutant loadings based on SWMM results.

The SWMM model was used to estimate volume and water quality of urban runoff within the City of Brady and to predict load reductions from various urban BMPs. This modeling effort was used to assist in location and sizing of urban BMPs that address the depressed dissolved oxygen and stormwater loadings of nutrients along this portion of the stream. The modeling effort assessed existing and post-BMP pollutant loadings to Brady Creek from relevant portions of the City of Brady for the purpose of evaluating effectiveness of BMPs and load reductions.

The SWAT model was set up to represent the watershed of Brady Lake. Sediment control provided by 35 aging flood-retention structures in the Brady Lake watershed plus potential water quality and enhanced water quantity benefits associated with brush control were the issues to be addressed with SWAT based on previously expressed stakeholder concerns. Further, SWAT output was used to provide the inflows to Brady Lake for the WRAP modeling system.

The WRAP modeling system contains several components, and those specific components that provide for water and salt balances were applied to Brady Lake. Increasing dissolved solids content has been experienced within Brady Lake over the years since its construction in 1963. Natural dissolved solids runoff is thought to be contributing to this issue, but the lake also rarely spills or releases waters and, as such, concentration of dissolved solids through evaporation is considered as an additional mechanism resulting in increasing dissolved solids. The WRAP modeling system allowed the importance of evaporation to be assessed as a factor in the lake's increasing dissolved solids concentrations and also assessed the benefits to lake storage from pumping WWTF effluent into Brady Lake. SWAT and WRAP were operated as a modeling system with SWAT providing the required lake inflow data for WRAP.

Using these model results, effective management strategies for reaching mitigation goals have been formulated. The key management measures developed include the installation of a series BMPs at 9 sub-basins that contribute oxygen depriving pollutant loads to Urban Brady Creek, coupled with pumping WWTF effluent to the upstream terminus of the Urban Brady Creek. The enhanced flow from the effluent pumping in tandem with a 50% reduction in pollutant loads to be achieved though the installation of hydrodynamic vortex separators in each of the 9 pollutant contributing sub-basins was selected by stakeholders as the most feasible management measures to implement. Restricted available space for constructing more conventional NPS pollution management measures precluded their consideration.

Information regarding the other management measures recommend by stakeholders, i.e. brush control in the upper basin above Lake Brady, sediment removal effectiveness of PL566 dams, and the information regarding pumping effluent into Brady Lake and the resulting effects on the lake's storage capacity and total suspended solids (TSS) concentrations were also evaluated.

A wide range of public outreach and education activities and methods was utilized by stakeholders to encourage public awareness and involvement in the development and implementation of the Brady Creek WPP.

A 12 year implementation schedule with associated costs and a 10 year monitoring plan was developed to guide future mitigation activities. It is recognized that implementation and monitoring of the recommended management measures will need to be tracked over time for evaluation purposes and to make adaptive changes if needed.

Finally, the WPP identified potential sources of funding for the management measures called for in the plan.

2.0 INTRODUCTION

The Brady Creek WPP aims to improve, protect, and maintain water quality within the Brady Creek watershed and to restore Urban Brady Creek which is impaired as a result of depressed DO (TCEQ, 2011). The plan includes an assessment of the causes of the depressed DO, the development of management measures to address the problem, and an implementation strategy to reduce nonpoint source (NPS) inputs and increased flows to meet water quality standards.

2.1 WATER QUALITY GOALS

The goal of the completed Brady Creek WPP is to give basin stakeholders a strategy that will result in the maintenance and restoration of water quality conditions consistent with the State of Texas Surface Water Quality Standards for the designated uses of the stream or water body. The Texas Surface Water Quality Standards establish explicit water quality goals throughout the state. The standards are set in an effort to maintain the quality of water in the state of Texas consistent with public health and enjoyment, protection of aquatic life, and the operation of existing industries and economic development of the state.

Basin-wide water quality goals established by the stakeholders include all stream segments within the watershed meeting the Texas Surface Water Quality Standards, achieving and maintaining appropriate levels of dissolved oxygen in impaired Urban Brady Creek, the deterrence of eutrophic conditions due to elevated nutrient loads, the prevention of excessive erosion and sediment deposition within the stream, the maintenance of water quality in Lake Brady, and, where possible, the maximization of stream base flows to restore or enhance aquatic utilization.

2.2 PURPOSE OF THE WATERSHED PROTECTION PLAN

A Watershed Protection Plan (WPP) is a plan developed by local stakeholders to restore and/or protect water quality and designated uses of a waterbody through voluntary, non-regulatory water resource management and through local regulations and ordinances. Public participation is critical throughout plan development and implementation, as ultimate success of any WPP depends on stewardship of the land and water resources by local landowners, business and residents of the watershed (Lake Granbury WPP, 2010). The Brady Creek WPP defines a strategy and an implementation plan to accomplish the goals of the stakeholders.

The primary purpose of the Brady Creek WPP is to eliminate the depressed DO problem in Urban Brady Creek and have this segment brought into compliance with state water quality standards and removed from the 303(d) list of impaired water bodies. The plan has goals and implementation strategies to accomplish this purpose.

2.3 ELEMENTS OF THE WATERSHED PROTECTION PLAN

The Brady Creek WPP has been developed under the auspices of the EPA through a 319(h) grant administered by TCEQ. To promote watershed-based planning, the EPA has outlined nine elements necessary to successful establishment of a WPP and the Brady Creek WPP satisfies each of these elements. The following steps provide a template for creation, implementation and review of watershed protection efforts. While the composition and strategy of watershed plans vary, the basic elements of any plan should include:

1. Identification of Causes and Sources of Impairment
2. Expected Load Reductions from Management Measures
3. Proposed Management Measures
4. Technical and Financial Assistance Needs
5. Information, Education and Public Participation Component
6. Schedule for Implementing Management Measures
7. Interim Milestones for Progress in Implementation
8. Criteria for Determining Pollutant Load Reductions and Water Quality Improvement
9. Load Reduction and Water Quality Monitoring Component

2.4 UPDATES AND REVISIONS

The Brady Creek WPP is a "living document," which can be updated and revised as new information emerges, management measures are implemented, and as progress toward attainment of goals are monitored. However, given the rural nature and modest population numbers existent in the Brady Creek watershed, stakeholders recognize that there are extremely limited local fiscal resources available for funding watershed improvement projects. They also recognize that it is financially unfeasible to hire a paid watershed coordinator for the Brady Creek watershed. Because of this fiscal reality, the stakeholders focused on cooperatively working with the City of Brady in identifying alternatives and potential modifications of their current WWTP improvement project plans. The focus was to permanently address the watershed's most pressing need, i.e. the remediation of the depressed dissolved oxygen impairment in urban Brady Creek. Water quality of Brady Creek will improve and short and long-term benefits, including the delisting of segment 1416A 03 from the 303(d) list, will come from the implementation of the strategies laid out in this document.

2.5 SUMMARY OF EXISTING WATER QUALITY CONDITIONS

Since the construction of Brady Lake in 1963, base flows in Brady Creek to downstream reaches have been severely curtailed. Through downtown Brady and immediate downstream reaches, stream flow has primarily consisted of urban runoff. Immediately below the City of Brady, high quality treated wastewater discharge from the City of Brady comprises almost 100% of the stream flow. Urban Brady Creek is comprised of perennial pools that harbor significant aquatic life, including recreationally important species. After the construction of the dam at Brady Lake and the resultant significantly diminished downstream flows, water quality has continuously degraded. The absence of scouring stream flows and perennial flows has resulted in the stream reach through urban Brady functioning primarily as a series of storm water ponds with intermittent stream flows. As a result, the stream often displays the characteristics of a eutrophic stream with prolific algae blooms, odors, and a generally unpleasant appearance.

There is a history of fish kills that have been investigated by the Texas Parks and Wildlife Department (TPWD) and TCEQ. Several fish kill reports prepared during the 1980s and 1990s by TPWD are included in Appendix E of the *Brady Creek Watershed Characterization*, included herein as Appendix A. Most of the TPWD reports connect the recorded fish kills with concurrent rainfall events. It has been concluded that most, if not all, of the fish kills were the result of NPS pollution from urban storm flows entering Urban Brady Creek.

Although there are concerns based on screening levels for nutrients and chlorophyll-a immediately below the discharge point of the city of Brady's WWTP (AU 1416A 02) and a concern based on screening levels for chlorophyll-a in Urban Brady Creek (AU 1416A 03), water quality in Brady Creek throughout the remainder of the Brady Creek watershed meets the State of Texas Surface Water Quality Standards.

2.6 PREVIOUS WATER QUALITY EFFORTS

In early 2000 both the TPWD and the TCEQ requested that the UCRA and the City of Brady pursue Clean Water Act (CWA) 319(h) funding to abate these NPS problems. In partnership with the City of Brady and the Lower Colorado River Authority (LCRA), the UCRA applied for and received funding for a two phase project. Phase I consisted of the development of an NPS Brady Creek Master Plan that included an evaluation of potential BMPs. Phase II included the construction of two demonstration BMPs and abatement projects.

The primary reason for initiation of the projects was to eliminate fish kills and deteriorating water quality conditions within Urban Brady Creek. The Master Plan identified and prioritized a number of urban BMP, and two structural BMPs selected from that plan were constructed. The first BMP, an instream low-head dam with a porous aeration basin below it, provides for increased dissolved oxygen within the creek. The second BMP is a series of gabion filter dams that intercept trash and debris before it enters the creek. Both BMPs included bank stabilization elements during their construction.

Subsequent to completion of the Master Plan, the EPA developed requirements for 319(h) grant participants that included the development of WPPs. WPP guidelines require the inclusion of 9 essential elements within each plan. Though the existing Brady Creek Master Plan did contain some of the 9 elements, it was recognized that all 9 were not met. Thus, the Phase II contract was amended to add work elements to allow for the creation of a watershed characterization pursuant to the ultimate preparation of a WPP for the entire Brady Creek watershed.

3.0 BRADY CREEK WATERSHED OVERVIEW

Many characteristics are important in determining the quantity and quality of water in a watershed, including climate, slope, vegetation types and densities, land use, amount of impervious ground cover, surface geology and soils composition, etc.. This section of the report presents both an overview of general watershed concepts and specific characteristics of the Brady Creek watershed.

3.1 GENERAL WATERSHED CONCEPTS

3.1.1 Watershed Definition

A watershed is an area of land across, through or under which water flows on its way to a single common point in a stream, river, lake or ocean. Watersheds include not only waterbodies such as streams and lakes, but also the surrounding lands that contribute water to the system during and after precipitation as runoff. Water quality and quantity can have significant effects on the function and health of a watershed. Conversely, activities in the watershed can have dramatic impacts on water quality and quantity. Watersheds can be extremely large, covering many thousands of acres and are often divided into smaller "subwatersheds" and even smaller "microwatersheds" for the purpose of study and management (Lake Granbury WPP, 2010).

3.1.2 Watersheds and Water Quality

To effectively address water issues, it is important to examine all natural processes and human activities occurring in a watershed that may affect water quality and quantity. Water from rainfall, snowmelt and irrigation that flows over agricultural, residential, industrial and undeveloped areas can carry pollutants into lakes, rivers, streams and oceans. Additionally, water from other sources containing pollutants may be released directly into a waterbody. To better enable identification and management, potential pollutants are classified based on their origin as to either point source or nonpoint source.

Point source pollution is pollution that is discharged from a defined location such as a pipe, ditch or channel. Point source pollution is typically deposited directly into a waterway and often contributes flow across all conditions, including both drought and flood. Point source pollution discharges must have a wastewater permit from the Texas Commission on Environmental Quality's (TCEQ) Texas Pollutant Discharge Elimination System (TPDES). These permits require specific pollutant limits for the effluent that aims to reduce the discharge's impact on the receiving waterbody.

Nonpoint source pollution refers to pollution that comes from a source that does not have a single point of origin. As the stormwater runoff from rain events moves over the land, it can pick up both natural and human-related pollutants, depositing them into waterbodies.

Ultimately, the types and amounts of pollutants entering a waterbody will determine the quality of water it contains and whether it is suitable for use for activities such as irrigation, fishing, swimming or drinking (Lake Granbury WPP, 2010).

3.1.3 Watershed Approach to Improve Water Quality

This Brady Creek Watershed Protection Plan was developed using a watershed-based approach. Because watersheds are determined by the topography of the landscape rather than political boundaries, watersheds often cross municipal, county and state boundaries. By using a watershed perspective, all potential sources of pollution entering a waterbody can be identified and evaluated.

Additionally, a watershed approach allows for all stakeholders in the watershed to be involved in the process. A watershed stakeholder is anyone who lives, works or engages in recreation in the watershed. They have a direct interest in the quality of the watershed and will be affected by planned efforts to address water quality issues. Municipalities, individuals, groups and organizations within a watershed can become involved as stakeholders in initiatives to protect and improve local water quality. Stakeholder involvement is critical for selecting, designing and implementing management measures to successfully improve water quality (Lake Granbury WPP, 2010).

3.2 BRADY CREEK WATERSHED INVENTORY

The Brady Creek watershed lies within the larger Colorado River basin, which in total drains over 40,000 square miles. of Texas from the New Mexico border across the state to its point of discharge into Matagorda Bay on the Gulf of Mexico near Matagorda (Figure 1). The headwaters of Brady Creek originate in western Concho County, thence flows east through Concho and McCulloch Counties to its confluence with the San Saba River in San Saba County (Figure 2). The Brady Creek watershed encompasses an area of approximately 513,000 acres. It is a tributary of the San Saba River.

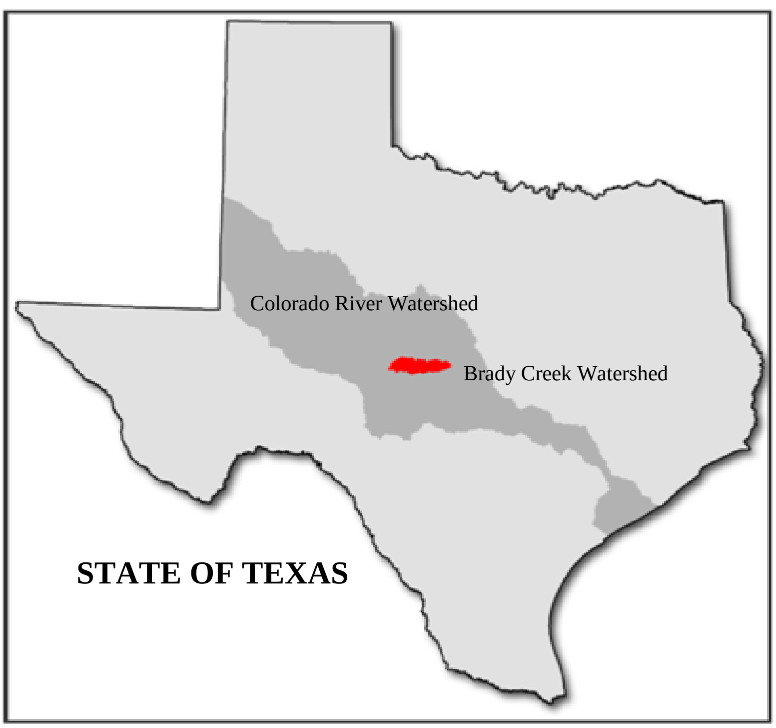


Figure 1 Brady Creek Watershed

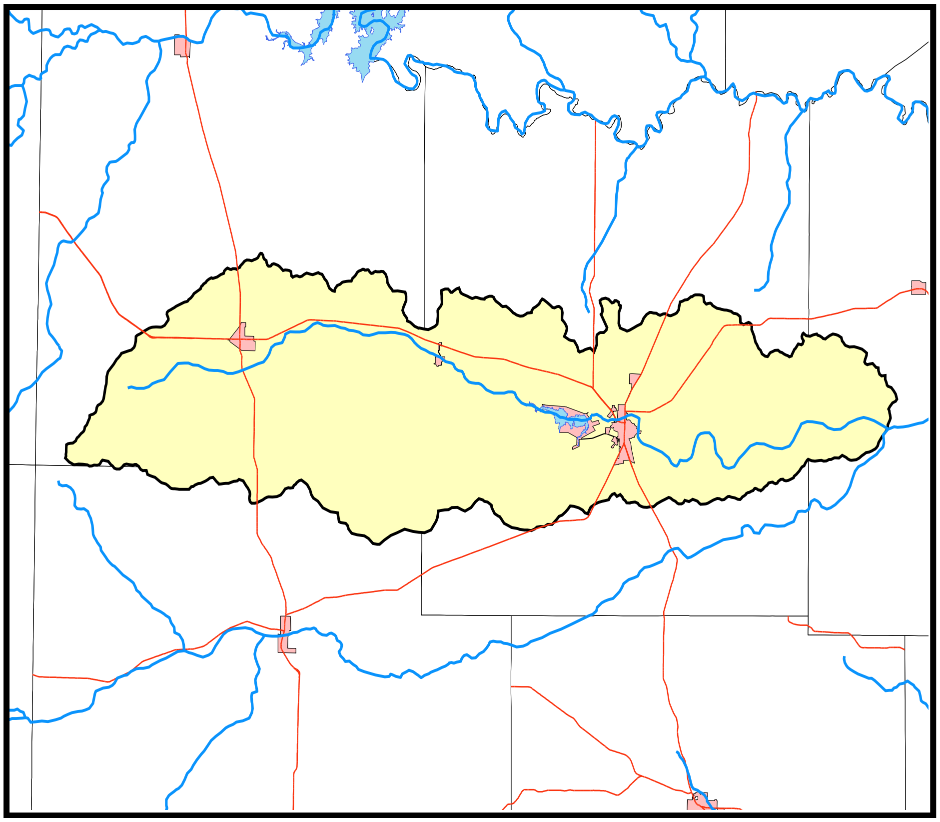


Figure 2 Brady Creek Watershed Boundary

The single most significant water body in the watershed is Brady Lake. The conservation pool elevation is 1743 feet, and at maximum capacity, the lake holds 29,110 acre feet of water. The lake was formed in 1963 when Brady Lake Dam was constructed as one part of a major flood prevention project implemented by the United States Department of Agriculture (USDA) Soil Conservation Service, now the Natural Resources Conservation Service (NRCS). Over a period of many years, this program was responsible for the construction of 42 other small watershed dams known as PL566 dams, many of which are located upstream of Brady Lake.

3.2.1 Hydrology

The watershed's hydrology was significantly and irrevocably altered in 1963 by the construction of Brady Lake Dam and by the 42 smaller PL566 dams located throughout the watershed that were constructed over a period of years. Prior to implementation of this flood prevention project, the City of Brady was periodically subjected to significant flood events and undoubtedly many positive benefits have resulted from the construction of these dams. Streamflow records from United States Geological Survey (USGS) flow gauging station 08145000 located at the US Hwy. 377 bridge near downtown Brady clearly illustrates the mitigating effect on flood flows realized by emplacement of the dams (Figure 3). However, there is no doubt that the resultant hydrologic transformation has negatively impacted the hydrologic function of Brady Creek, most notably downstream of Brady Lake. Not only have flood flows been mitigated, base flows have also diminished. This is illustrated by flow duration curves constructed for a 20 year pre-dam emplacement period and from a 2001-2012 post-dam emplacement period (Figure 4) The post-dam emplacement period is shorter because the USGS gage ceased operation between October 1, 1965 and April 25, 2001.

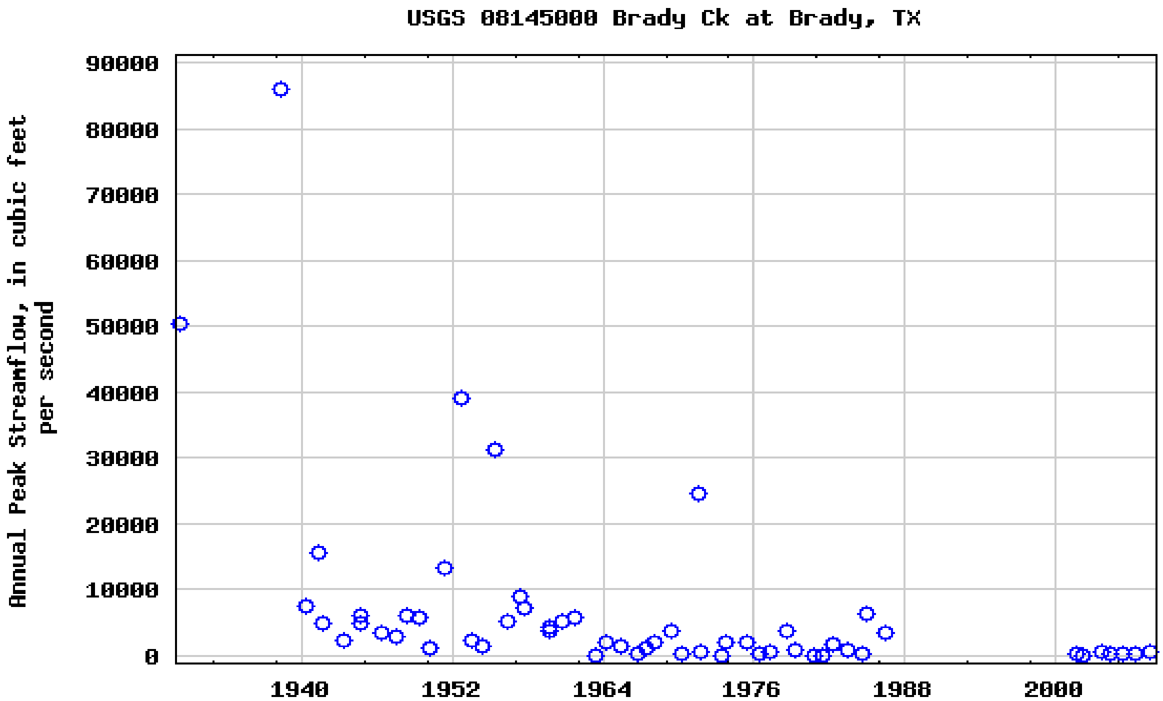


Figure 3 **Brady Creek USGS Gaging Station 08145000 streamflow data**

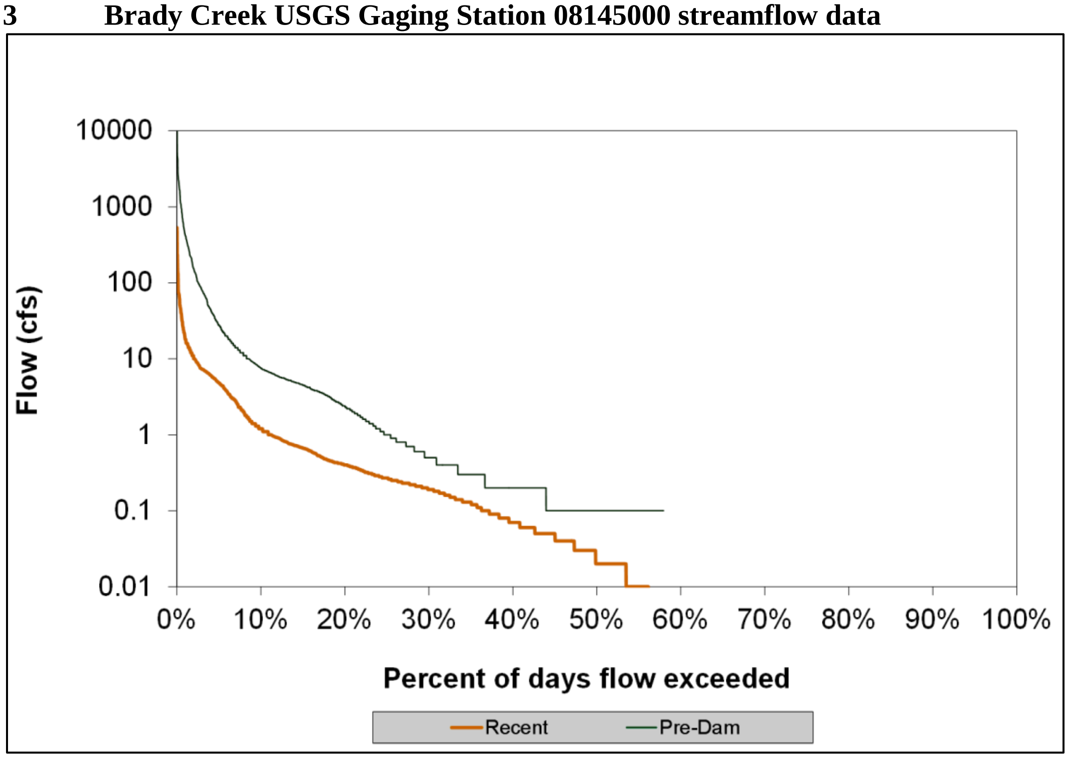


Figure 4 Flow duration curves for Brady Creek near North Bridge Street (USGS gage 08145000). Recent period is 2001 –2012 data and pre-dam period is 1940 – 1962.

The almost complete absence of scouring flood flows and perennial base flows in the Urban Brady Creek stream reach has resulted in Brady Creek functioning primarily as a series of storm water retention ponds with intermittent stream flows. As a result, the creek often displays the characteristics of a eutrophic stream with depressed levels of the DO, prolific algae blooms, odors, and a generally unpleasant appearance.

Upstream of Brady Lake, Brady Creek exhibits intermittent base flows with few perennial pools. Long time residents report that base flows have significantly declined since construction of the flood prevention dams and the encroachment of mesquite, juniper, and salt cedar over the previous several decades. Although there is little supportive data, it is likely that the anecdotal observations are accurate and historical base flows were once greater than now experienced. Storm flows and potential flood flows in the upper portion of the basin are controlled by the NRCS flood control structures. The base flows that do exist are likely sustained by groundwater inflows from the shallow alluvial aquifer, discussed in the geology section.

Base flows in the portion of Brady Creek located immediately downstream of Brady are mostly provided by wastewater discharge that influences the stream flow for a few miles. Base flows in this reach are estimated to average close to 1 cubic foot per second, which approximates the quantity of effluent discharged by the Brady WWTF. In the lower portion near the San Saba River confluence, base flows increase to 6-8 times the base flows immediately downstream of the Brady WWTF. This flow increase is contributed from springs and seeps originating in the surface limestone and dolomite beds that outcrop in the area.

3.2.2 Geology

West of Brady Lake, Brady Creek and its major tributaries head out in predominantly limestone rocks. These waterways traverse alluvial deposits composed mostly of sand, gravel and caliche which overlie and are in contact with sandstones or alternating beds of clay, shale, limestone and/or dolomite. Water quality data indicate that salinity levels increase in Brady Creek from its headwaters to Brady Lake. This observed pattern is likely attributable to contributions of naturally occurring, relatively saline water that originates from the dissolution of chlorides from the bedrock, which at some locations form the floor of shallow alluvial aquifers. These thin, shallow aquifers intermittently contribute base flows to Brady Creek and its tributaries. North of the Brady Creek Watershed, where these same bedrock formations are exposed at the surface, the names given to several Colorado River tributaries are indicative of naturally occurring saline contributors. These include Salt Branch, Salt Creek, and Salt Gap (for which the small community of Salt Gap was named). It is reasonable to assume that these same rocks, which are present in the shallow subsurface in the Brady Creek Watershed, not only contribute saline groundwater to the aforementioned alluvial aquifers, but also directly contribute saline water to Brady Creek in areas where the bedrock is exposed in the stream channel.

East of Brady Lake, Brady Creek traverses a short stretch (approximately 4-5 miles) of much older rock beds that consist of sandstone, shale and limestone sequences that do not contain significant amounts of chloride bearing minerals. It is therefore assumed that these rocks do not contribute significant amounts of saline waters to the creek. This assumption is supported by water quality data obtained from ambient monitoring samples collected from this stretch of the creek. For the remainder of its stream reach, Brady Creek and its tributaries traverse mostly clean limestone and dolomite. The observed water quality from this stretch is also significantly better than the aforementioned quality west of Brady Lake. Through this downstream reach, Brady Creek is a gaining stream and typically experiences more persistent flows of relatively improved quality from groundwater discharged into it from these outcrops (Brune, 1975).

3.2.3 Soils

The soils located in a narrow three to four mile band along the main channel of Brady Creek consist mainly of clay and silty clay loams. Because the parent materials of the soils consist of carbonate rocks (limestones and dolomites), the soils are typically calcitic. These soils are deep, well drained and exhibit moderate to moderately slow permeability. They typically exist on the relatively flat flood plain near the channel, exhibit gentle slopes (typically less than 5%), and have a low runoff potential and erosion hazard (UCRA, 2010b). It is in these areas that most of the farming activity that occurs in the watershed is located. Although the cultivated farmland found along and near the main channel poses the greatest man-made risk for soil erosion, most producers invest considerable resources to prevent soil erosion and it is not presently a significant, recognized concern.

The soils located further from the main creek channel consist of shallower clay and silty clay soils, also calcitic. These are typified as being well drained with moderately slow permeability. The slopes for these soils are mostly less than 20%, with the majority being in the 5% or less range It is only along and near drainage features that higher degrees of slope exist, and even in areas of 5% to 20% slopes, runoff potential and erosion hazard is moderate (UCRA, 2010b). These soils are used mainly for ranching.

In the predominantly limestone hills that form the margins of the watershed, the soils are mostly clay and gravelly clay loams. These soils are shallow to very shallow with rock outcrops exposed in some areas. They are typically well drained and exhibit medium slow permeability. The runoff potential is negligible to moderate and the erosion hazard is moderate except in areas with extreme slopes (UCRA, 2010b). These areas are mostly used for rangeland and wildlife production.

Overall, the potential hazard from erosion is not considered a significant recognized concern in the Brady Creek Watershed. Soil conservation practices utilized by producers and the previously mentioned flood prevention dams located along the waterways throughout the watershed successfully mitigate potential soil erosion concerns. Due to the parent materials from which they were developed, most of the soils present in the watershed are calcitic. Although this attribute might result in an increase of hardness, it is of no importance as a water quality issue. The soil column is not a major contributor to the observed salinity increases in Brady Creek. A generalized soils map derived from the NRCS STATSGO Database (NRCS, No Date) is included in Figure 5.

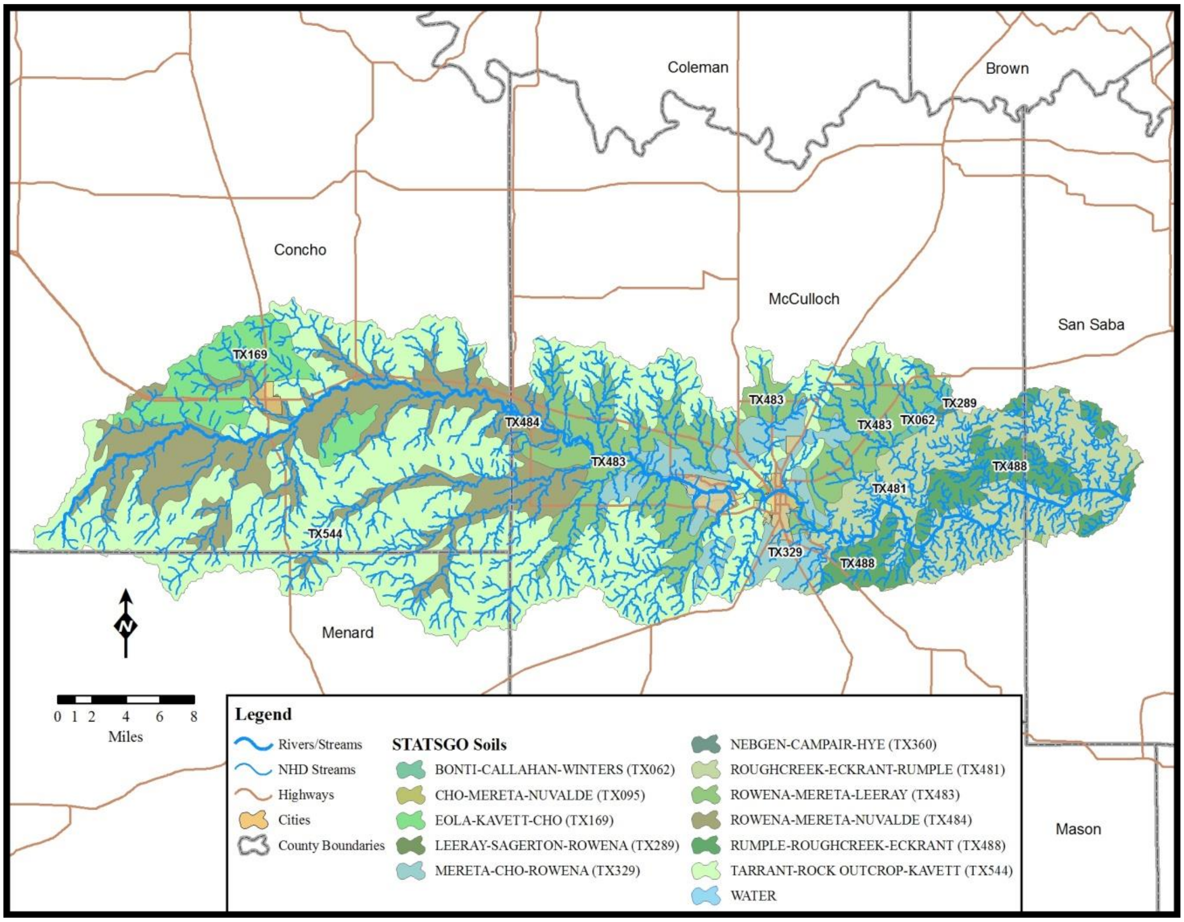


Figure 5 Brady Creek Watershed Soils Map

3.2.4 Climate

Brady Creek watershed, much like most of West Texas, receives a majority of its rainfall from thunderstorms through the spring and into the fall season. These storms tend to be relatively brief and sometimes, intense. Due to tropical influences in the late summer and fall, the highest rainfall month is normally September or October, with the second highest period being in May each year. Because of the obvious relationship with storm water and NPS issues, some definitions as to typical storm types encountered in the region have been provided. As a result, a normally intense storm is one that would produce in excess of one inch of rainfall within a two hour period, but no more than two inches within the same period; and a normally minor storm as one that would produce less than one half inch of rainfall within a two hour period. These extremes define the range for the majority of storms experienced within the watershed.

To define what a typical storm event might be, several factors have been considered that have a major impact on storm water quality. First, storm intensity may have a major impact on storm water pollutant loading as high runoff velocities tend to transport more materials during strong storms. Small and moderate storms tend to generate less runoff quantitatively and produce less scouring velocities. Conversely, very small storms following extended dry periods could produce high concentrations of pollutants, although total loadings would still remain lower. The time since significant rainfall may also have a significant effect on runoff quality. The longer the period since the last rainfall, the greater the pollutant loading is likely to be. As noted above, the word intensity was used to describe storm events in lieu of the total rainfall accumulation. Intensity in this context means rainfall during a specific span of time, usually expressed as inches per hour.

Climate Averages for Brady, Texas are as follows (UCRA, 2010b):

Annual Average Temperature:	65°F
Monthly Average High Temperature:	
January	59°F
July	95°F
Monthly Average Low Temperature:	
January	32°F
July	82°F
Annual Average Precipitation:	23.2 inches
Annual Average Snowfall:	0.25 inches
Growing Season:	226 days
Prevailing Winds:	South

3.2.5 Ecology, Wildlife and Vegetation

The Brady Creek watershed is located at the boundary of the Central Rolling Plains and the Edwards Plateau physiographic regions of Texas. Topographic elevations range from about 1300 feet above sea level at its eastern margin to about 2000 feet above sea level at its western margin, for total relief of about 900 feet. In general the land surface is gently rolling to semi level except along drainage features where slopes increase.

The ecology of the watershed reflects a history of negative disturbances including overgrazing, declining native grasslands and altered river ecosystems. Historic grassland rolling prairies are now mesquite and juniper dominated. There are no known endangered or endemic aquatic species present in Brady Creek

Brady Lake, which is primarily fed by storm generated flows from Brady Creek, is a recreationally important water body utilized extensively for fishing, boating, camping and swimming. Although the reservoir is almost 50 years old, the quality of sports fishing continues to be maintained at a high level. Although many common Texas fish species are present in the lake, Largemouth Black Bass and Crappie appear to be favorites with fisherman there. The quality of the fishery is likely due to abundant cover and structure in the reservoir which favors these species. The lake basin is home to at least one invasive plant species, salt cedar. It appeared in the lake basin several years ago and is thriving and increasing its range. A fish kill that occurred in late winter of 2012 was attributed to golden algae (P. parvum).

Brady Creek in the Brady urban area has perennial pools with significant aquatic life, including recreationally important native species such as bass, crappie, panfish and catfish. A portion of the Creek is included in the TPWD's Urban Fisheries Program and receives periodic stockings of rainbow trout and channel catfish when aquatic conditions allow. As previously mentioned, the urban portion of Brady Creek has been negatively affected by the cessation of base flows due to the construction of Brady Lake Dam in 1963. Since then, it functions hydrologically more like a series of storm water retention ponds rather than a healthy stream system.

Downstream of the City of Brady, Brady Creek traverses native pastures with typical Texas Hill country surroundings and is normally perennial from this point to its confluence with the San Saba River. Excessive algae production in the upper reaches of this portion of the creek is attributed to the treated wastewater effluent that is discharged by the Brady wastewater treatment plant. However, this condition rapidly decreases downstream with biological assimilation and dilution from naturally occurring groundwater inflows, rendering this stream reach supportive of high-quality aquatic use.

Terrestrial wildlife species throughout the watershed are typical of the Texas hill country, with whitetail deer, turkey, and quail having recreational and economic significance. One exotic species, the Axis deer, has increased in numbers and currently maintains a significant population. Feral hogs have also been identified by the stakeholders as problematic.

3.2.6 Land Use and Population

Land use within the upper portion of the watershed above Brady Lake is a mixture of open rangeland and cultivation. The majority of the cultivated land is located along the flood plains of Brady Creek and some tributaries. The dominant crop is small grains, but cotton is also produced in some fields. The urban areas of Eden and Melvin are located in the upper watershed. Both of these municipalities are small in areal extent. Eden has a population of approximately 2,500 persons, approximately half of which are inmates housed in the Eden Detention Center, a federal prison located there. Melvin has fewer than 200 residents.

The landscape of the middle portion of the basin is dominated by Brady Lake and the City of Brady. This area includes agricultural use, residential development, park lands, commercial development, and industrial sites (Figures 6 and 7). The land use determinations and map were derived from the 2001 National Land Cover Database (NLCD, 2001). Based on the 2010 census population of 5,553 and a land area of 8.98 square miles, the City of Brady had a population density of 615.7 persons per square mile (US Census, 2010).

The lower portion of the watershed is comprised almost completely of rangeland. There no organized development and population within the area is sparse.

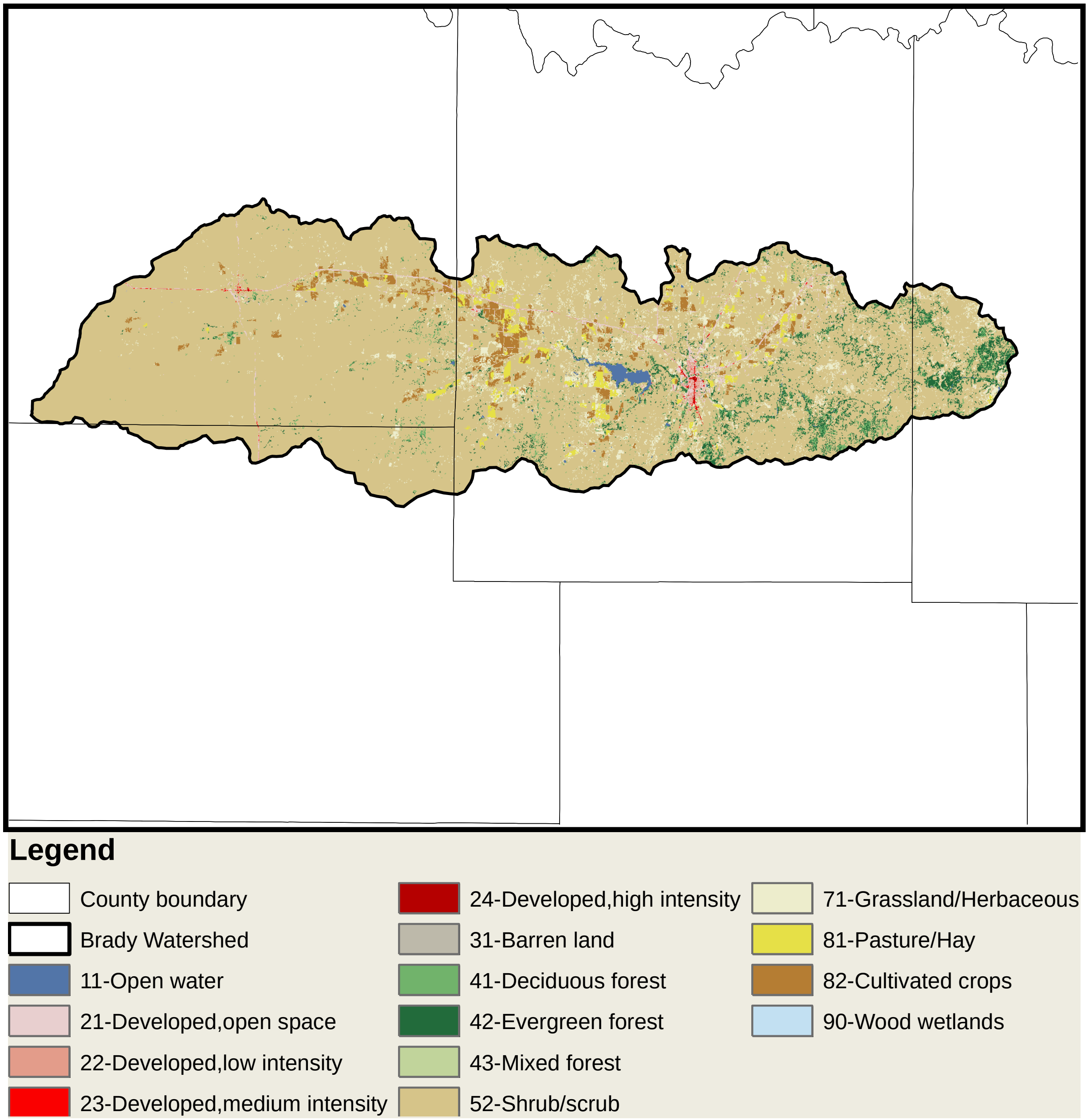


Figure 6 Brady Creek Watershed Land Use Map

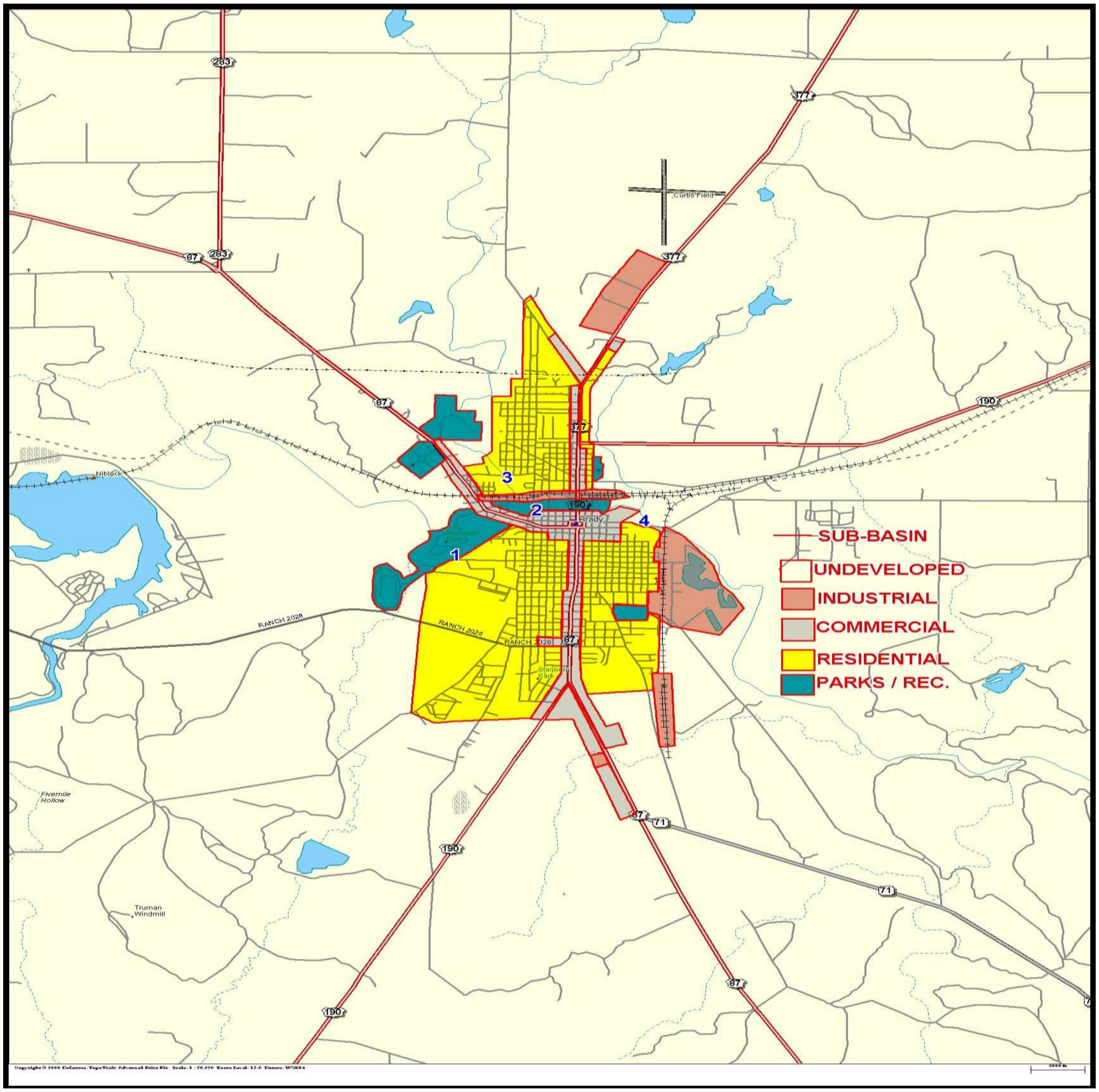


Figure 7 City of Brady Land use Map

4.0 BRADY CREEK WPP STEERING COMMITTEE

4.1 GOAL

The Brady Creek WPP Steering Committee (the Committee) is an informal organization of landowners, agricultural producers, city, county and municipal local business and industry representatives and concerned citizens working to improve conditions in the Brady Creek watershed. The goal of the Committee is to develop and implement a Watershed Protection Plan that will result in the maintenance and restoration of water quality conditions consistent with the State of Texas Surface Water Quality Standards for the designated uses of the stream or water body. The strategies presented in this report are a product of Committee member's input and direction.

The Committee considered the potential impact of water quality, the economic feasibility and affordability of strategies, and existing regional and local governmental planned activities into the development of the WPP.

4.2 TECHNICAL ADVISORY GROUP

The Brady Creek WPP is a collaborative effort of many state and federal agencies and the Committee. Technical support and logistical leadership have each been provided by the Technical Advisory Group. Grant funding for the project has been provided by the EPA and administered by TCEQ. The Technical Advisory group consists of representatives from TCEQ, UCRA and the Texas Institute of Applied Environmental Research (TIAER). Their role was to facilitate the Committee and help with technical and logistical knowledge and water quality expertise.

4.3 BRADY CREEK WPP STEERING COMMITTEE

The Committee is the decision-making body for the development of the WPP. Stakeholders and the Committee chose to adopt a consensus-based decision making process policy rather than a formal voting process. Consensus means overwhelming agreement is defined as everyone being able to live with the decisions made. Methods of dealing with potential unresolved conflicts of the stakeholders or the Committee are included in the Public Participation Plan written and approved by TCEQ for this WPP project. While some issues of conflict arose during the course of stakeholder meetings, ultimately, in every case a consensus agreement was achieved.

The Steering Committee consisted of stakeholder representatives from all but the easternmost geographic areas of the Brady Creek watershed. (Stakeholders from the downstream easternmost portion of the watershed did attend meetings, but none volunteered for service on the Steering Committee).The committee consisted of citizens from the City of Eden, the Community of Melvin, The City of Brady, a McCulloch Co. SWCD representative, and rural landowners.

While formation of the Committee was facilitated by the Technical Advisory Group, the Committee is an independent group of watershed stakeholders with an interest in restoring and protecting the designated uses and overall health of Brady Creek. The membership of the Committee reflects the diversity of interests within the Brady Creek watershed. Categories of stakeholders sought for the group followed the guidance provided in the EPA's *Handbook for Developing Watershed Plans to Restore and Protect our Waters.*

4.4 WORKGROUPS

No formal work groups were created by the committee.

4.5 PARTICIPATION BY THE GENERAL PUBLIC

While the Committee was the formal decision making body for the development of the WPP, it was recognized that other watershed stakeholders could also provide valuable input. To that end all Committee meetings were open to the public and all stakeholders had unlimited access. The Committee benefitted from having several active watershed residents that also participated in the process even though they were not formal members of the Committee.

From stakeholder meeting sign-in sheets, a total of fifty-nine individuals participated in one or more of the meetings. However it is likely that a number of individuals attended and participated in meetings but failed to include their names on the sign-in sheets.

4.6 STAKEHOLDER IDENTIFICATION OF ISSUES OF CONCERN

The stakeholder group participated heavily in discussions and decision-making. The group provided valuable input and local insight and was involved in the identification and approval of appropriate issues that the WPP should address. The group was also involved not only in the decision-making process regarding potential strategies to pursue, but also the selection and approval of final strategies identified in the WPP.

Issues brought up in stakeholder group meetings included the following:

- Melvin salt seep complaint
- golden algae problem in Lake Brady and resulting fish kill
- concern for diminished stream flows below Brady and land valuation impacts
- functionality and maintenance of PL566 dams and diminished flows into Brady Lake
- feral hog population
- education regarding illegal dumping
- salinity in Brady Lake
- depressed DO in Brady and inclusion on the 303(d) impaired water body list
- pumping of wastewater effluent to Brady Lake, Richards Park, and/or the golf course
- sediment erosion and riparian management throughout the watershed
- dredging and channelization between Melvin and Eden to improve flow
- periodic releasing of water from Lake Brady
- nutria burrowing into banks increasing erosion and sedimentation
- brush encroachment in the upper basin potentially affecting stream flow
- the affect of San Angelo's use of Hickory aquifer
- oil and gas activity and impacts to water quality, groundwater and surface water

- city of Melvin's use of septic systems, no public wastewater system
- education on best types of grasses to plant and riparian areas for erosion control

Many of these issues never rose to a level of concern beyond discussions held and explanations provided during stakeholder meetings. The following concerns were collectively approved as appropriate issues to be included in the WPP. Based on the approved watershed characterization and discussions held in meetings, the highest priority concern identified was addressing the depressed DO problem in Urban Brady Creek and working toward it's delisting as an impaired waterbody. Coupled with this concern was the issue of maintaining stream flows below Brady with treated effluent. Other concerns deemed appropriate for further evaluation and inclusion in the WPP were the causes of increasing salinity in Brady Lake, the effect on flows into Brady Lake from brush encroachment and the functionality and maintenance of PL-566 dams in the upper basin.

5.0 WATER QUALITY MONITORING

5.1 LINKING WATERSHED WATER QUALITY

Watersheds are determined by the landscape and not political boundaries. They often cross municipal, county, state and even national boundaries. Regardless of whether watersheds encompass large or small land areas, the activities of humans such as agriculture, industry and property development within a watershed have an effect on the amount of pollutants and sediments that are delivered into waterbodies. Natural processes also impact water quality through evaporation, vegetative transpiration, precipitation, infiltration and the decomposition of organic matter, and an understanding of the function of these processes is helpful in assessing current conditions. Moreover, because a watershed represents a basin that drains into a common water body, investigation of climate, land use, human activity, geology, hydrology and soil types of the entire watershed factor in to the equation of water quality. By evaluating the impact of pollutants on these natural processes and systems, watershed planners can simulate the potential impact of pollutants within the watershed. Using models to perform these simulations is a particularly good method of assessment and evaluation because they allow for multiple scenarios to be analyzed and provide predictive capabilities that allow estimations of future outcomes based on variable assumptions.

5.2 AMBIENT WATER QUALITY MONITORING

TCEQ evaluates the condition of the state's water bodies on a biennial basis as required by Sections 305(b) and 303(d) of the federal Clean Water Act (CWA). The results are published in the *Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(b)*. This report, formerly called the *Texas Water Quality Inventory and 303(d) List* describes the status of Texas' natural waters based on historical data, including concerns for public health, fitness for use by aquatic species and other wildlife, and specific pollutants and their possible sources. It identifies water bodies that are not meeting Texas Surface Water Quality Standards set for their use in a section called the 303(d) List. Water bodies that are included on the 303(d) list are referred to as "impaired."

The Texas Surface Water Quality Standards establish explicit goals for the quality of streams, rivers, lakes, and bays throughout the state. The Standards are developed to maintain the quality of surface waters in Texas so that it supports public health and enjoyment and protects aquatic life, consistent with the sustainable economic development of the state.

These water quality impairments are identified by comparing concentrations in the water to numerical criteria that represent the state's water quality standards or screening levels to determine if the waterbody supports its designated uses, such as suitability for aquatic life, for contact recreation, or for public water supply. This process determines if fish and aquatic insects have adequate oxygen, if people swimming in the water are exposed to pathogens that may cause illness and if the water is fit to be used as a source for public drinking water.

Water quality standards numerical criteria are used by TCEQ as the maximum or minimum instream concentrations that may result from permitted discharges and/or nonpoint sources and still meet designated uses. To resolve the issues of regional and geological diversity of the state, standards are developed for classified segments. Classified segments are defined segments of waterways that are unique from other segments, and appropriate water uses such as contact recreation, public water supply, and aquatic life are assigned to each segment. Sometimes, the segments consist of smaller spatial units called assessment units (AU) that collectively delineate the segment.

However, many streams are not classified segments, and are designated as unclassified segments. These unclassified segments, of which Brady Creek is one, do not have specific water quality standards developed for them. For assessment purposes, unclassified streams are assessed using the numeric criteria developed for the classified segments into which the stream flows.

The Surface Water Quality Monitoring (SWQM) Program administered by TCEQ coordinates the collection of ambient water quality samples from more than 1800 surface water sites statewide and maintains a database of the results. These data are used to determine compliance with the Texas Surface Water Quality Standards. The Texas Clean Rivers Program is a state funded water quality monitoring data assessment and public outreach program that contributes ambient water quality monitoring data to the SWQM Program. Five monitoring stations used in the collection of data for these programs are located within the Brady Creek watershed (Table 1, Figure 8). Analytical results from samples collected from one of these stations provided ambient water quality data used in the Brady Creek WPP.

Moreover, as part of this WPP, ambient monitoring was conducted monthly at five sites, three of which were also used for storm water monitoring, established for this WPP along Brady Creek from the headwaters of the Creek to its confluence with the San Saba River (Table 1 and Figure 8). Sixteen monitoring events were conducted on these sites and data obtained from this monitoring were used as data inputs to the models developed for the Brady Creek WPP.

5.3 STORM WATER MONITORING

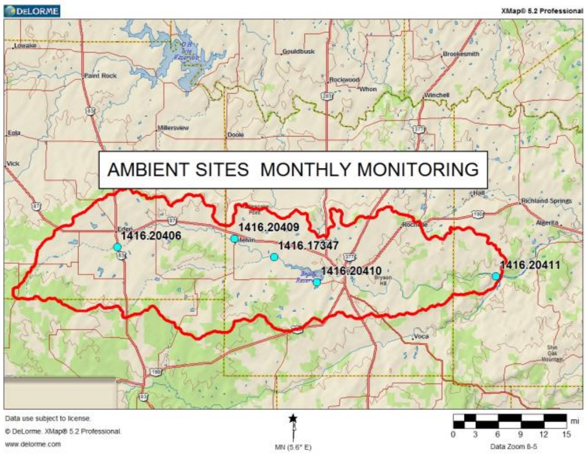
In addition to ambient monitoring, seven sites (four urban and three rural) were chosen as locations on which perform a minimum of three storm water monitoring events each (Table 1 and Figure 8). As previously mentioned, three of these sites were used for ambient and storm water monitoring. Persistent drought conditions precluded conducting the planned number of urban and rural stormwater monitoring events. Consequently, only two urban stormwater monitoring events at each of two sites (20067 and 20811) and one event at urban site 20812 were carried out.

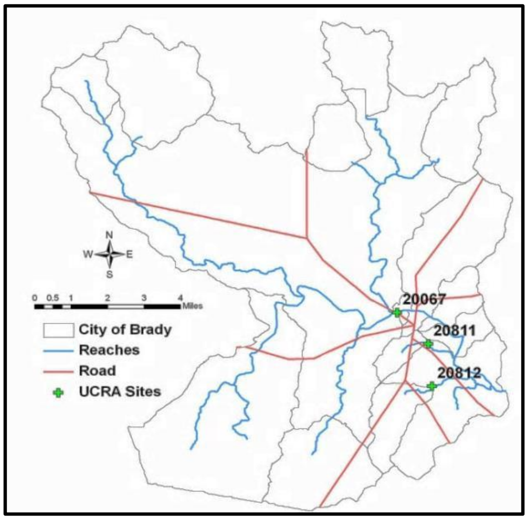
Storm water monitoring in the rural portions of the watershed were similarly affected by drought conditions, decreasing the number of stormwater monitoring event opportunities that occurred during the data collection period. Also, the spatial characteristics of storms affected the number of rural storm events that were carried out. The results of these events and their use in the modeling process are discussed in the following sections of this WPP.

Table 1 Monitoring Site Information

TCEQ Station ID	Site Description	Latitude Longitude	Ambient Site	Storm Water Site Rural	Storm Water Site Urban	SWQM Site
1416.20067	#1 Storm Water Sub-basin E	N31°.13707” W99°.33894”			YES	
1416.20811	#2 Storm water Sub-basin B	N 31°7.425” W 99° 19.594”			YES	
1416.20812	#3 Storm water Sub-basin A	N 31°6.297” W 99°19.485”			YES	
1416.14232	#4 Storm water TCEQ SWQM Site	N 31°6.725” W 99°18.736”				*YES
1416.20406	#5 Storm water Ambient Site “A”	N 31° 10.057” W 99° 29.594”	YES	YES		
1416.20409	#6 Storm water Ambient Site “B”	N 31° 12.221” W 99° 34.875”	YES	YES		
1416.17347	#7 Storm water Ambient Site “C”	N 31° 10.057” W 99° 29.594”	YES	YES		YES
1416.20410	Ambient Site “D”	N 31° 7.130” W 99° 23.837”		YES		
1416.20411	Ambient Site “E”	N 31° 7.738” W 98° 59.664”		YES		

*Site #4 not used (no access to site)





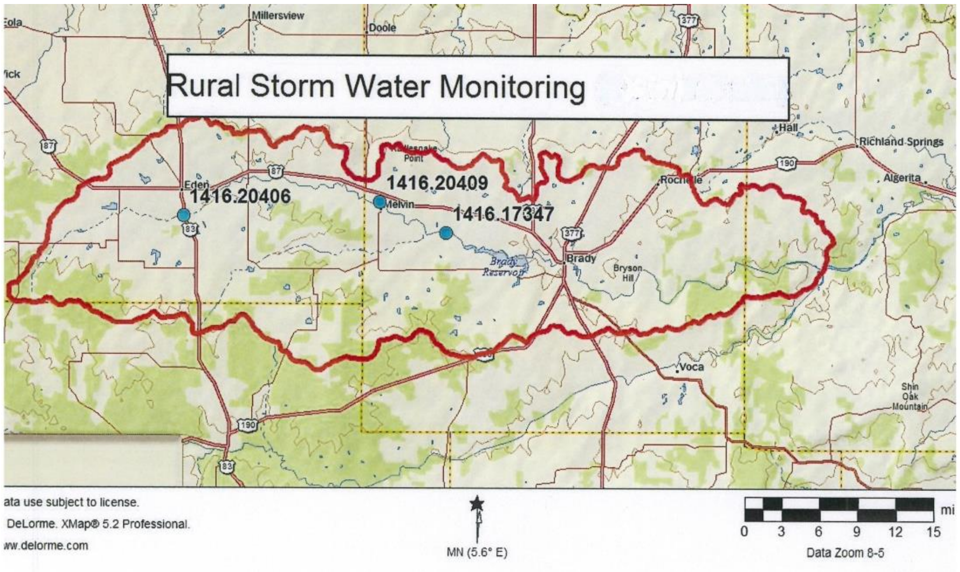


Figure 8 **Ambient Monitoring Sites and Urban and Rural Storm Water Monitoring Sites**

6.0 BRADY CREEK WPP MODELING PURPOSE AND SELECTION

In order to determine pollutant loads from unimpaired portions of the watershed, to determine more precise pollutant loadings from the impaired urban watershed within the city of Brady, and to evaluate depressed dissolved oxygen along Urban Brady Creek, the Texas Institute for Applied Environmental Research (TIAER) was contracted to develop and apply appropriate computer models. Specific models and modeling activities were chosen to address stakeholder concerns and satisfy Elements A through C of the nine required elements of a watershed protection plan. Most of the information included in this section of the WPP is taken from the *Brady Creek Watershed Modeling Study Supporting Watershed Protection Plan Development* report, either in summary form or as direct excerpts. The report in its entirety is included as Appendix B.

The modeling activities conducted for the WPP utilized data from the approved *Brady Creek Watershed Characterization* in conjunction with data collected during development of the WPP. All data collection and modeling activities were performed in accordance with provisions in the *Brady Creek Watershed Protection Plan QAPP* in the *Modeling Efforts for the Brady Creek Watershed Protection Plan QAPP*.

The models used during the development of the WPP served to supplement and refine the pollutant loading estimates provided in the *Brady Creek Watershed Characterization* and identify the causes and sources of pollution that contribute to the depressed DO impairment. They were used to assist in the evaluation of various management measures and scenarios, for the selection of appropriate BMPs, for the determination of load reductions needed to achieve identified goals, and to estimate load reductions that may be obtained from the implementation of selected management measures. The modeling report also provides details and descriptions of the structural BMPs and management measures and processes that will need to be implemented to achieve required load reductions.

Four models were selected for the Brady Creek WPP. For the Urban Brady Creek portion of the watershed, the Storm Water Management Model (SWMM) and the QUAL2K model were chosen. The SWMM model was applied to evaluate urban pollutant loadings within urban areas of the city of Brady and the QUAL2K model was applied to evaluate possible control measures that may reduce occurrences of depressed oxygen in the Urban Brady Creek. The SWAT model was chosen to evaluate stakeholder concerns regarding sediment control provided by PL-566 dams and potential benefits from brush control in the Brady Lake watershed. Using SWAT model outputs, the water and salt balance components of the Water Rights Analysis Package (WRAP) modeling system were applied to Brady Lake to evaluate likely increasing salinity in the reservoir. As previously mentioned, existing data as well as newly acquired water quality data, were used as inputs to the models to evaluate environmental issues in the Brady Creek watershed and to address needs for estimating loading reductions.

6.1 QUAL2K MODEL SELECTION

Mechanistic computer models can be used to study the impact of oxygen demanding substances (e.g., carbonaceous biochemical oxygen demand (CBOD) and NH_3-N), aquatic vegetation, and other factors (e.g., sediment oxygen demand or SOD) on DO and assist in evaluating alternative control measures for situations of unacceptably depressed DO concentrations. Models provide analytical abstractions (or simulations) of the real system, such as the Urban Brady Creek for this study. Mechanistic models, also referred to as process models, are based on theoretical principles. The models can provide for representation of governing processes that determine the response of certain state variables (model outputs). For this project, DO is the primary output of interest, though other state variables (e.g., streamflow, water temperature, CBOD, NH_3-N, and suspended algae) will also be discussed. Under circumstances where the governing processes are acceptably quantifiable, as is the case for DO, the mechanistic model provides understanding of important biological, chemical, and physical processes in the real system (that is, Urban Brady Creek) and predictive capabilities to evaluate BMPs.

A consideration in the model selection process is the prevailing hydrology of the stream system under the water quality conditions of greatest concern. The Urban Brady Creek is the domain or system to be modeled, because it is the TCEQ defined segment where the depressed 24-hour minimum and average DO concentrations occur along the Brady Creek in Texas. Because of the influence of Brady Creek Reservoir on streamflows of Urban Brady Creek and the relatively low rainfall for the area, the creek does not experience many stormwater pulses and from that perspective the hydrology does not fluctuate to the degree measured in many Texas streams and rivers located further east in the state. These factors allow the Urban Brady Creek to be modeled using a steady-state model that assumes relatively constant flows over the period being simulated. (The flow can vary in the longitudinal direction increasing or decreasing with distance downstream, but at any location the flow should be relatively steady.)

In the past, QUALTX has been used as the standard water quality model in Texas for assessment of DO and it is the standard steady-state DO model employed by TCEQ for waste load allocations and other applications where steady-state hydraulic conditions may be assumed and 24-hour average DO is the primary state variable of concern (TCEQ, 2010a). Because of the present limitation of QUALTX to simulate diel (24-hour) DO fluctuations and its inability to provide a 24-hour minimum DO, a different model had to be considered to evaluate the depressed DOs of Urban Brady Creek. The U.S. Environmental Protection Agency (USEPA) supported model, QUAL2K, was selected. QUAL2K has similar capabilities to those of QUALTX with the added dimension of simulating diel variations in water quality, which provides the model capabilities to simulate absolute minimum DO for a 24-hour period as well as the 24-hour average DO. QUAL2K is a relatively recent model that was developed to provide a modernized version of QUAL2E that was finding more limited applicability because it cannot be operated under operating systems.

QUAL2K provides for the prediction of water quality in river and stream systems by representing the channel in a one-dimensional, longitudinal manner with the assumption of vertical and lateral complete mixing. The model allows branching tributaries, provides non-uniform, steady flow hydraulics, and water quality variables are simulated on a diel time scale. Excel workbook serves as the interface for QUAL2K. Model execution, input and output are all implemented from within Excel. Visual Basic for Applications (VBA) serves as Excel's macro language for implementing all interface functions, and numerical calculations are implemented in FORTRAN 90 (Chapra et al, 2008). QUAL2K version 2.11 was applied to develop the Urban Brady Creek model.

6.2 SWMM MODEL SELECTION

The Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (Huber and Dickinson, 1988; Rossman, 2009). As described in the user's manual (Rossman, 2009), SWMM was first developed in 1971; has undergone many upgrades over the years; and consists of runoff, transport and tracking components. The runoff component operates on a collection of sub-catchment areas that receive precipitation and generates runoff and pollutant loads. The transport component takes this runoff through a drainage system network of pipes, channels, storage/treatment devices, pumps, and regulators. Then SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel. Thus SWMM has capabilities of simulating the generation and transport of runoff flows, estimating the production of pollutant loads associated with this runoff, and predicting changes in water quantity and quality as a result of management decisions and storage/treatment devices (e.g., wet and dry ponds).

The SWMM model was selected for application because of its capabilities to simulate conditions in urban watersheds. SWMM Version 5.0, representing an extensive rewriting of the code into a Windows compatible mode, was used in this study and represents a collaborative effort of EPA and the consulting firm of CDM, Inc. (Rossman, 2009). The SWMM model was applied to estimate peak flows, storm volumes and water quality of urban runoff within the City of Brady and to evaluate load reductions from proposed urban BMPs.

6.3 SWAT MODEL SELECTION

SWAT is a physically-based watershed and landscape simulation model developed by the USDA-Agricultural Research Service (Arnold et al., 1998). Major components of the model include hydrology, weather, erosion, soil, temperature, crop growth, nutrients, pesticides and agricultural management. SWAT also has the ability to predict changes in sediment, nutrients (such as organic and inorganic nitrogen and organic and soluble phosphorus), pesticides, dissolved oxygen, bacteria and algae loadings from different management conditions in large un-gauged basins. SWAT operates on a daily time step and can be used for long-term simulations. The model output is available in daily, monthly and annual time scales. SWAT has been successfully applied to model water quality issues including sediments, nutrients and pesticides in watersheds.

SWAT was selected for application because of the need to simulate conditions on a watershed and landscape scale, to address stakeholder concerns regarding the condition of numerous aging PL-566 reservoirs located in the watershed, and to evaluate the potential to benefit agricultural productivity and water availability by means of brush control. SWAT meets all of these needs by virtue of the fact that it is well adapted to agricultural and rural watersheds, contains features to allow the inclusion of small reservoirs, and is one of the preferred models in Texas for evaluating brush control benefits on the water balance of a watershed.
Moreover, the SWAT model was selected to provide input in the form of streamflows to the WRAP model of Brady Lake discussed in the next section.

The 2009 version of SWAT was used for this application (http://swat.tamu.edu/documentation/).

6.4 WRAP MODELING SYSTEM SELECTION

The WRAP modeling system was developed by Dr. Ralph Wurbs, Texas A&M University (e.g., Wurbs, 2005, 2009, 2010, 2012b). WRAP is a water resources management simulation system for rivers and reservoirs that has been incorporated into the Water Availability Modeling (WAM) System implemented and maintained by TCEQ. The WRAP modeling system is comprised of several programs and features. The reservoir water balance and salt balance components were the features leading to its selection for application to Brady Lake. Because the WRAP model operates on a monthly time-step, the desired outputs of end-of-month storage volume and monthly average TDS concentrations for Brady Lake could be predicted.

It was selected to address concerns of interest groups in the Brady Creek watershed regarding elevated TDS concentrations occurring in Brady Lake, which detract from the usefulness of the lake as a source of municipal drinking water for the City of Brady. The WRAP model was selected to investigate the role of lake evaporative losses on salinities and the potential benefits to lake volume of pumping wastewater into Brady Lake. It involved a combination of two models. The SWAT model discussed in the previous chapter was selected to provide the surface runoff into Brady Lake and the WRAP modeling system was applied to Brady Lake to evaluate salts and reservoir storage volume.

7.0 QUAL2K MODEL APPLICATION (URBAN BRADY CREEK)

7.1 BACKGROUND TO QUAL2K MODEL VERIFICATION PROCESS

Model calibration and validation are collectively referred to as model verification. Calibration is the first stage testing and tuning of a model to a set of observational data, such that the tuning results in a consistent and rational set of theoretically defensible input parameters. Validation is subsequent testing of a calibrated model to additional observational data to further examine model validity, and preferably under different external conditions from those used during calibration (Thomann and Mueller, 1987).

Hence, calibration is a systematic procedure of selecting model input parameters to progressively improve the comparison of model predictions to observational data. For the present study, the adjustments of input parameters were constrained within literature-suggested ranges from such sources as TNRCC (1995) and Bowie et al. (1985). For any input parameters without literature values or direct measurements within the project area, expert judgment was used. In the calibration step, the model predictions of the critical parameters of 24-hour average and minimum DO were conservatively low, but well within the goal set for the model application.

Within the separate validation step, the input parameters defining such things as kinetic rates remain at the values used in the calibration step, and separate sets of observational data are used for comparison purposes. In the event model predictions for the validation step are unacceptable based upon visual inspection of graphical data comparisons, the model validation process requires recalibration to the measured validation data sets and then re-validation against the calibration data sets. In the application of QUAL2K to Urban Brady Creek, the validation step provided fairly good results, but some minor additional fine tuning of a couple of input parameters was required, which necessitated the re-validation step.

The goal of validating the model in such a way is to obtain a robust model capable of making reliable predictions of DO concentrations under a variety of environmental conditions. Additional information on the subject is provided in the project's modeling QAPP (UCRA & TIAER, 2012).

Water Quality Verification Data

AU 1416A_03 is described as Brady Creek from Ranch Road 714 upstream to Brady Lake dam. It has been included on the 303(d) list of impaired water bodies since 2004 and remains listed in the 2012 Integrated Report. (TCEQ, 2012). For purposes of QUAL2K modeling, only the portion of creek between RR 714 upstream to immediately above the large pool in Richards Park was included. This reach is referred to as Urban Brady Creek in this WPP (Figure 9). The portion of AU 1416A_03 upstream of Urban Brady Creek to Brady Lake dam is rural without any road crossings or public access and without any historical water quality data.

Figure 9 **Urban Brady Creek**

The water quality data available for AU 1416A_03 was obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS). The station monitored within AU 1416A_03 is 17005 located at the Elm Street low-water crossing of Brady Creek. The water quality for model verification was reduced to those data that included 24-hour data from deployment of a multiprobe and water quality parameters related to DO, such as nutrients (Table 2). Since samples collected at station 1005 for analysis of other water quality parameters were typically not collected at the same time as the multiprobe deployments, the temporally nearest water quality data collected at station 17005 within one month of the deployment were also considered part of the verification dataset, but only if no significant storm pulses of elevated flow occurred between the deployment and the other sampling date. Because of unsteady flows from a small stormwater runoff event, the 4-5 March 2005 24-hour multiprobe deployment event was excluded from consideration in the verification datasets and is not included in Table 2.

A total of six 24-hour events were considered acceptable for the model verification process. The last 4 events (12-13 September 2005, 20-21 March 2005, 18-19 September 2006, and 19-20 March 2007) were used for the calibration step and the first two events (4-5 August 2002 and 22-23 August 2005) were used for the validation step. The decision for separating the datasets was based on the greater abundance of water quality data for the last 4 events and the desire to have at least 4 datasets for the calibration process. The amount of water quality data available for the model verification process was not optimal, since a greater number of 24-hour events would have been beneficial to more thorough model verification as well as other water quality parameters being collected at the time of the multiprobe deployments. A larger set of data for model verification would have provided for a more thorough testing of both model performance and confidence in model results and reduced the uncertainty associated with simulation results. Nonetheless, the amount of water quality data is adequate considering that Brady Creek is an unclassified water body and that the actual area of depressed DO is but a small portion of the entire length of segment 1416A.

Table 2 SWQMIS water quality data used in verification process for QUALK2K

Start Date	End Date	CHLA	DO24Avg (mg/L)	DO24Max (mg/L)	DO24Min (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	NO2+NO3-N (mg/L)	PO4-P (mg/L)	TP (mg/L)	TOC (mg/L)	TSS (mg/L)	WTemp24Avg (℃)	WTemp24Max (℃)	WTemp24Min (℃)
08/05/02	08/05/02	—	—	—	—	—	—	—	0.283	—	—	—	—	—	—
08/04/02	**08/05/02**	—	3.9	5.3	2.7	—	—	—	—	—	—	—	29.0	29.9	27.3
08/22/05	08/22/05	—	—	—	—	—	0.37	<0.02	—	0.14	—	—	—	—	—
08/22/05	**08/23/05**	—	1.1	2.0	0.2	—	—	—	—	—	—	—	29.1	31.6	25.1
09/12/05	**09/13/05**	—	3.2	4.9	1.5	—	—	—	—	—	—	—	26.3	26.9	25.6
10/13/05	10/13/05	—	—	—	—	0.97	0.06	0.10	<0.04	0.12	7.5	35	—	—	—
02/21/06	02/21/06	70.4	—	—	—	1.11	<0.02	<0.02	<0.04	0.10	8.6	14	—	—	—
03/20/06	**03/21/06**		9.7	12.4	7.5	—	—	—	—	—	—	—	14.9	16.2	13.5
04/17/06	04/17/06	41.2	—	—	—	1.61	0.03	<0.02	<0.04	0.10	9.6	20	—	—	—
08/15/06	08/15/06	266.0	—	—	—	4.01	<0.02	0.02	<0.02	0.45	18.7	98	—	—	—
09/18/06	**09/19/06**	—	3.2	5.8	0.7	—	—	—	—	—	—	—	24.2	25.4	22.6
10/11/06	10/11/06	36.5	—	—	—	1.26	<0.02	<0.02	<0.02	0.20	10.5	29	—	—	—
02/27/07	02/27/07	111.0	—	—	—	1.62	<0.02	<0.02	<0.02	0.18	9.3	32	—	—	—
03/19/07	**03/20/07**	—	6.8	10.1	4.3	—	—	—	—	—	—	—	19.3	19.9	18.9

(Dates in bold typeface indicate diurnal monitoring events, remainder are grab sample dates.)

Urban Brady Creek is 3.0 km (1.9 mi) long. Because the tributaries to the Urban Brady Creek are for the most part highly ephemeral, the model representation became relatively simple; one main stem without tributaries (Figure 10). Further, Urban Brady Creek has no WWTF outfalls or other point sources that needed to be included in the model segmentation. QUAL2K is structured to allow a representation of a water body, such as Urban Brady Creek, by dividing it longitudinally into reaches that can have unique hydraulic features (e.g., bottom width, rating curves for the two relationships of velocity and water depth to flow). A reach can be subdivided into a user specified number of equal-length elements. It is at the element level that the model provides its water quality and hydraulic predictions. Urban Brady Creek was divided into a total of 9 reaches and a total of 31 elements (Table 3, Figure 10). On average each element represented about 0.1 km (0.06 mile or 330 feet) of Urban Brady Creek.

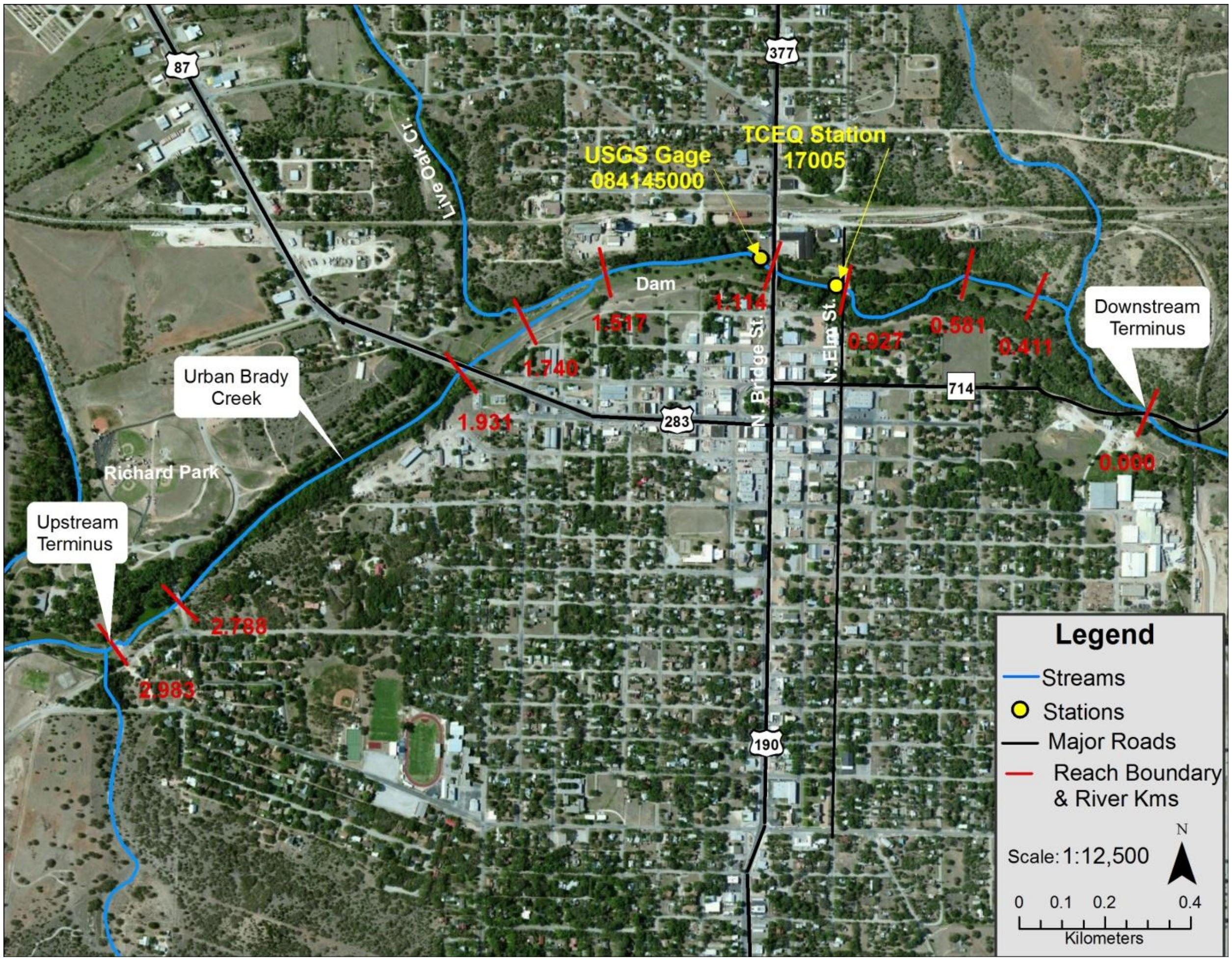


Figure 10 **Urban Brady Creek QUAL2K Segmentation**

Table 3 **Urban Brady Creek QUAL2K segmentation information**

Upstream Label	Downstream end of reach label	Reach #	Length (km)	Upstream (km)	Downstream (km)	Number of Elements
Upstream Dam	Bridge to Richards Park	1	0.20	2.983	2.788	2
Bridge to Richards Park	US 87	2	0.86	2.788	1.931	9
US 87	Confluence with Live Oak Cr.	3	0.19	1.931	1.740	2
Confluence with Live Oak Cr.	Small Dam between US 87 & N. Bridge St	4	0.22	1.740	1.517	2
Small Dam between US 87 & N. Bridge St	N. Bridge St/I377/I190	5	0.40	1.517	1.114	4
N. Bridge St/I377/I190	N. Elm Street	6	0.19	1.114	0.927	2

N. Elm Street	To pond btwn N. Elm St. & RR 714	7	0.35	0.927	0.581	4
To pond btwn N. Elm St. & R 714	End of pond btwn N. Elm St. & RR 714	8	0.17	0.581	0.411	2
Dwnstrm of pond btwn N. Elm St. & RR 714	RR 714	9	0.41	0.411	0.000	4

The application of the QUAL2K model verification process required various other inputs and data including reaeration inputs, meteorological inputs, kinetics and temperature effects, point and diffuse sources, sediment oxygen demand (SOD) and sediment, nutrient release rates, specification of headwater conditions, and bottom algae and SOD coverage. Input parameters were adjusted to improve the comparison of predictions to measured data, and the range of adjustment was constrained within literature-suggested ranges from such sources as TNRCC (1995) and Bowie et al. (1985). For any input parameters without direct measurements within the project area, literature values and expert judgment were used in the calibration process. Each of these inputs, their functions and how the model uses them is discussed in detail in the *Brady Creek Watershed Modeling Study Supporting Watershed Protection Plan Development* (the modeling report) (Appendix B).

7.2 QUAL2K MODEL VERIFICATION

The Urban Brady Creek QUAL2K model was calibrated and validated to a total of six different measured conditions using water quality data collected within the period of 2005 - 2007. It was only during this 3-year period that 24-hour DO data were collected in Urban Brady Creek at station 17005. The last 4 events (12-13 September 2005, 20-21 March 2006, 18-19 September 2006, and 19-20 March 2007) were used for the calibration step and the first two events (4-5 August 2002 and 22-23 August 2005) were used for the validation step (Table 2).

For the calibration and validation periods, the model was operated for 30-days wherein the model considers the hourly meteorological input data set as being same for each day. By trial and error it was determined that it takes several days in the model for the relatively slow growing bottom algae to approach equilibrium conditions. To ensure that equilibrium biomass conditions were approached, the model was operated for 30-days. According to Dr. Steve Chapra, primary author of QUAL2K, a common error in applying QUAL2K is to not simulate a sufficient number of days to allow bottom algae to approach equilibrium (Chapra, 2006).

7.2.1 QUAL2K Model Calibration

The QUAL2K model of the Urban Brady Creek (Segment 2311) was calibrated for the most part by visually comparing model predictions to measured data using the graphical features associated with the model. Input parameters were adjusted to improve the comparison of predictions to measured data, and the range of adjustment was constrained within literature-suggested ranges from such sources as TNRCC (1995) and Bowie et al. (1985). For any input parameters without direct measurements within the project area and literature values, expert judgment was used in the calibration process.

The philosophy of the model calibration process was that streamflow and water temperature would be forced to match very closely, if not exactly, so that their influence on water quality would be as accurately reflected in the QUAL2K model as possible. The other water quality parameters, besides temperature, would then be calibrated separately.

Initially, in most cases water temperatures were under predicted by the model when compared to observed data. This was attributed to a cooling effect caused by the presence of vegetation along the creek banks that reduced wind speed and decreased evaporation resulting in increased water temperatures. A wind sheltering coefficient less than 1.0 was multiplied by the observed wind speed to achieve acceptable water temperatures.

QUAL2K Calibration Input Data

Global kinetic rates that applied to each reach in the segmentation were used as the preferred model input whenever acceptable calibration could be obtained. When spatial definition of kinetic rates by reach was required, this specification occurred within the Reach Rates sheet (Table 4 of the modeling study) (Appendix B). Global kinetic rates were predominately used. Spatially varying rates were defined only for pooled areas along the creek.

SOD rates and nutrient fluxes into the water from the sediment were predicted by the model, which is controlled in the model. The model allows the user to prescribe SOD rates and nutrient fluxes when the sediment diagenesis algorithm is operative, as they were for all applications to Urban Brady Creek. In Chapra et al. (2008) it is mentioned that this prescription option is provided to account for situations where organic matter has been deposited during periods outside of the steady state period being studied (e.g., during runoff events, from fall and winter leaf fall, previously existing sedimentation). For Urban Brady Creek, user prescribed SOD rates and nutrient fluxes were used to characterize urban stormwater contributions. The prescribed SOD and nutrient fluxes were input in conjunction with externally applied temperature adjustments.

QUAL2K Calibration Output

The calibrated model predictions are presented as graphical results with observational data provided on the same graphs. Based on a comparison of measured and predicted DO, the model reasonably predicted DO during the four calibration periods (Figures 11 - 14). The goal of the calibration was to predict the minimum 24-hr DO within +/- 2 mg/L and the average 24-hour DO within +/- 1.5 mg/L and this goal was largely obtained.

In each of the simulations, the impact of pooled areas in depressing DO is evident. In non-pooled reaches of Urban Brady Creek, Higher DO concentrations were observed. This occurrence has implications not only on model calibration and validation but also on evaluating the efficacy of control measures.

Other important water quality parameters predicted by QUAL2K include the inorganic nutrient forms (i.e., NH_3-N, NO_{23}-N, PO_4-P). These nutrients were often measured below reporting limits (see Table 2). An example of several of the numerous model output parameters are provided in Figures 15 and 16. Note that for the measured values on these two figures, a maximum and minimum measured concentration is provided on each graph. The maximum plotted value is the reporting limit and minimum value is zero. The actual value could be anything between those two extremes. More quantitative information on calibration of these water quality parameters is provided in the modeling report (Appendix B).

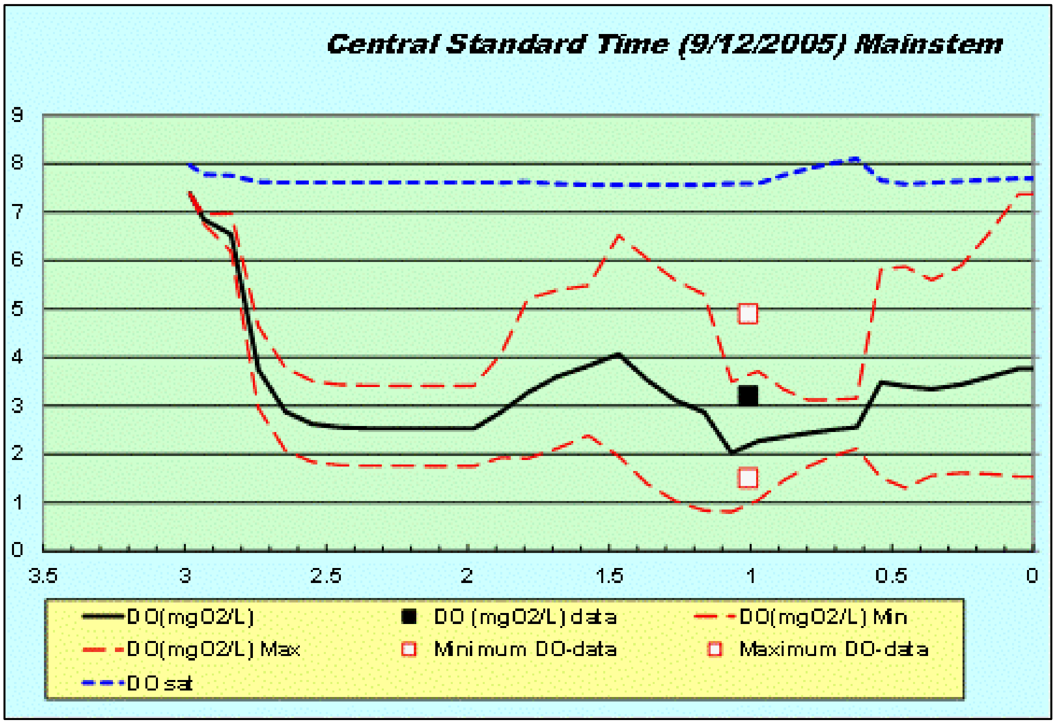


Figure 11 **Calibration results for QUAL2K for 12-13 September 2005**

Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L

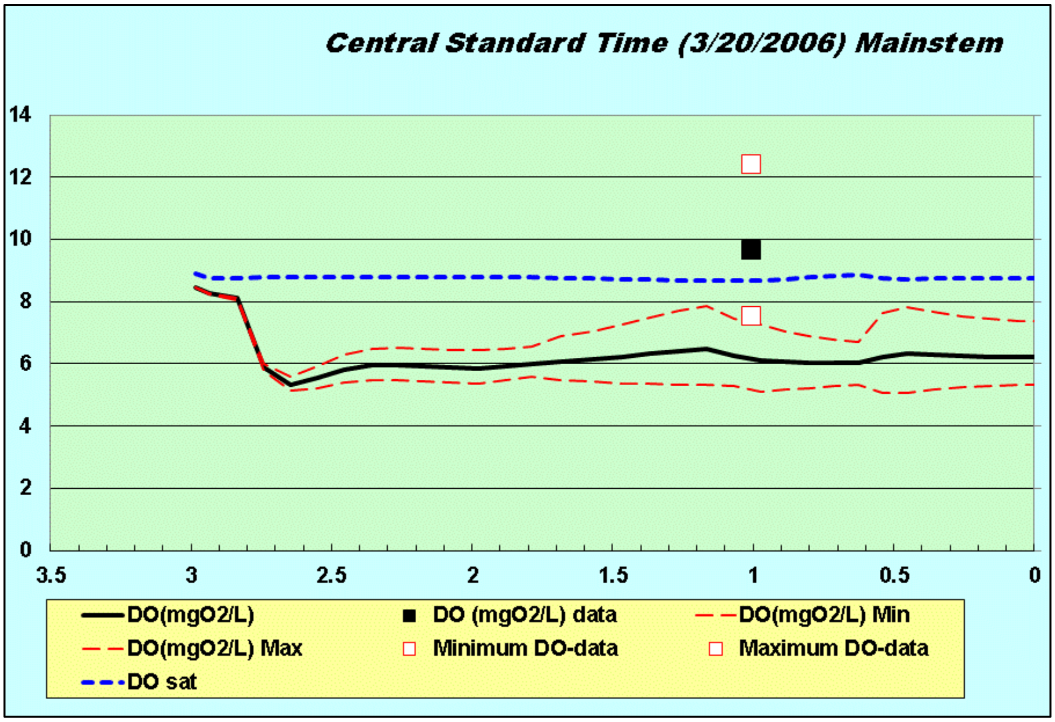


Figure 12 **Calibration results for QUAL2K for 20-21 March 2006**
(Model incapable of predicting measured supersaturation DO concentrations; Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L)

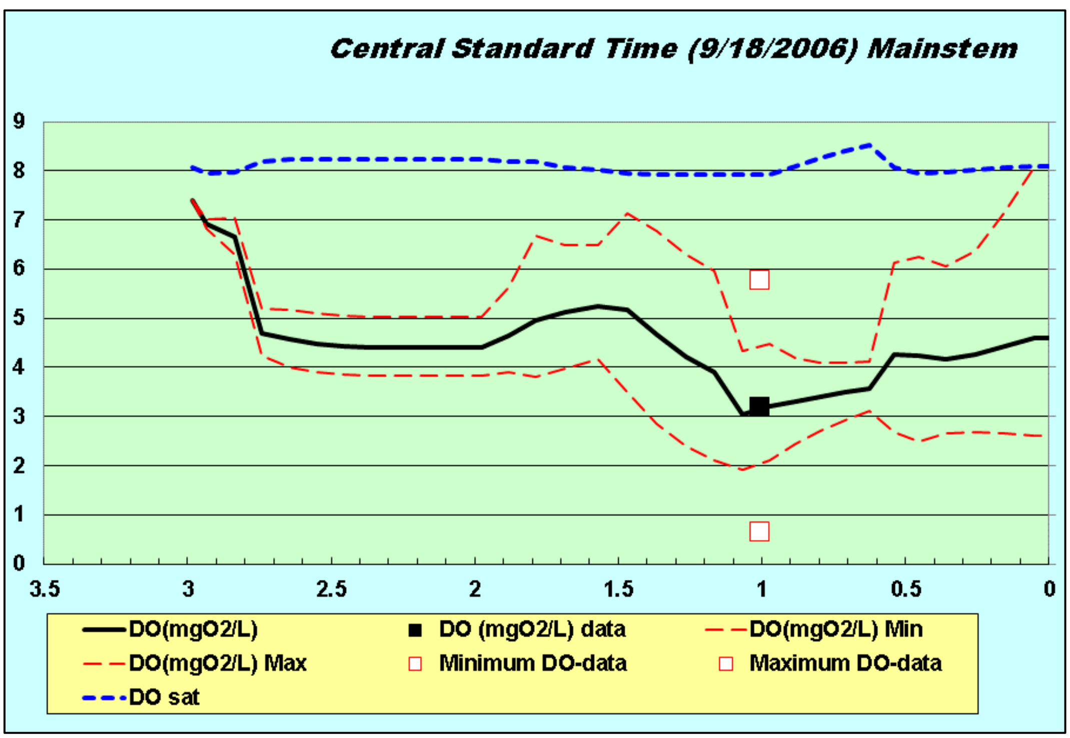


Figure 13 **Calibration results for QUAL2K for 18-19 September 2006**
Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L

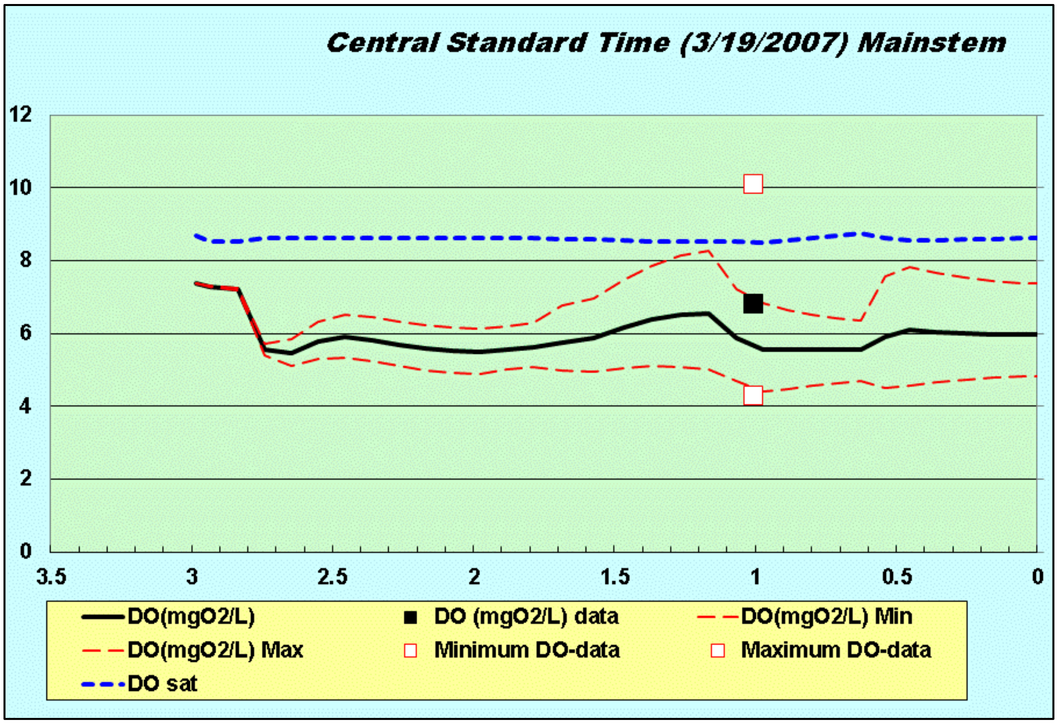
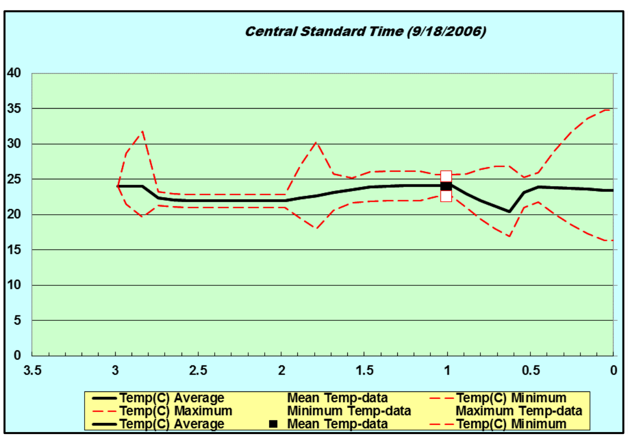
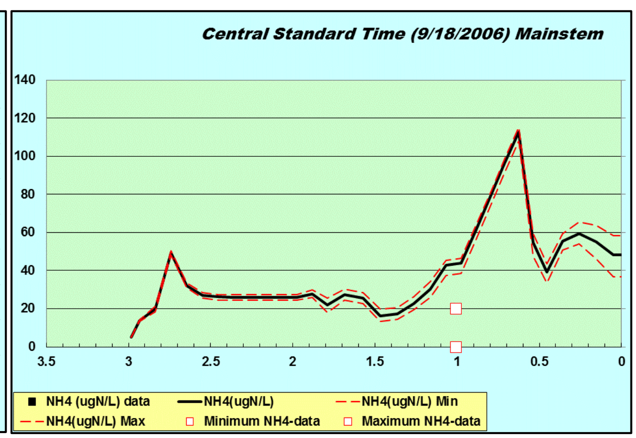


Figure 14 **Calibration results for QUAL2K for 19-20 March 2007**
Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L





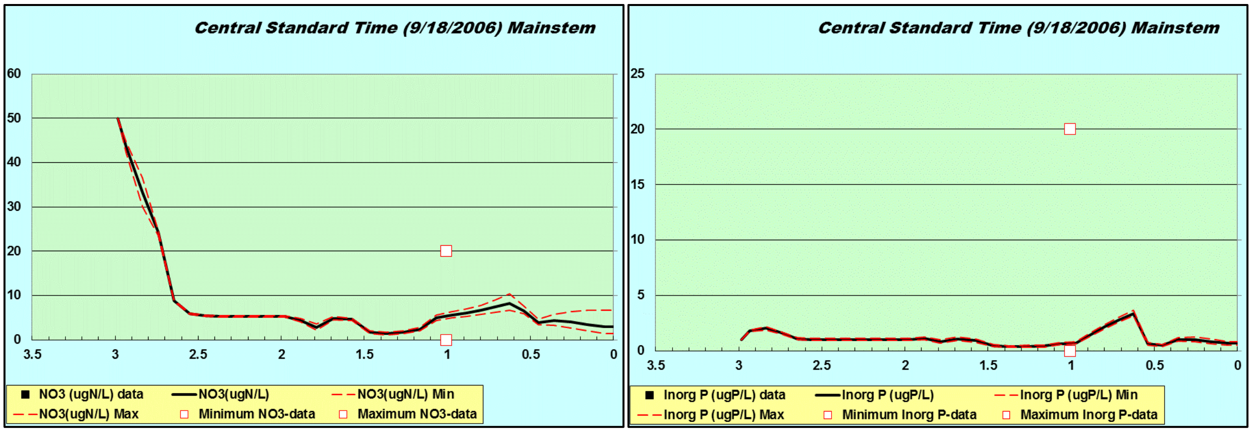


Figure 15 QUAL2K output showing measured vs. predicted water temperature, NH_4-N_{23}, and PO_4-P (inorganic P)

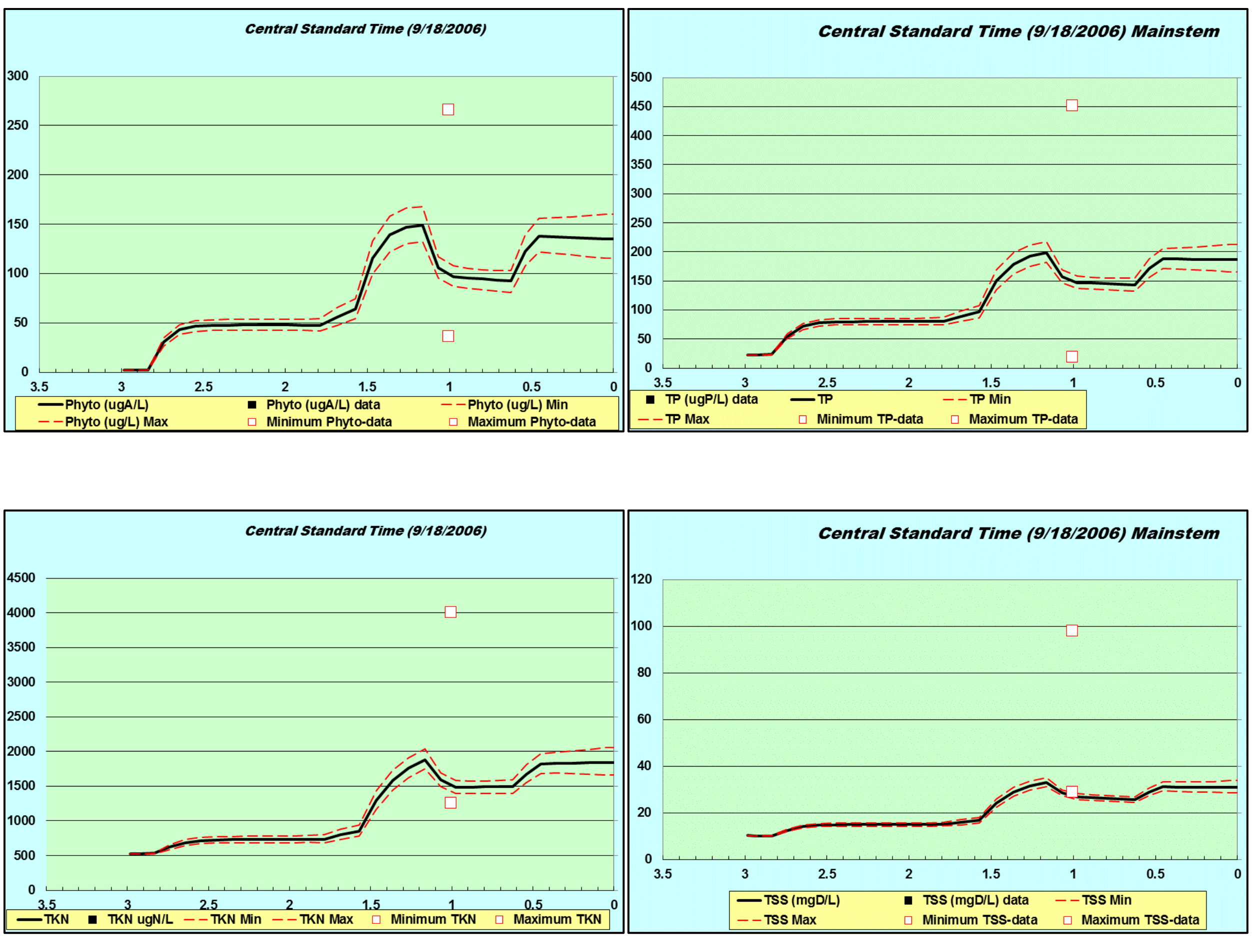


Figure 16 QUAL2K output showing measured vs. predicted phytoplankton (CHLA), total-P, TKN, and TSS

7.2.2 Model Validation

As with the model calibration, the model validation predictions are presented as graphical results with measured data provided on the same graphs. In the validation step, the model was operated with the same input developed during the calibration step except for those parameters that were time dependent, such as meteorological data and streamflows. The two validation scenarios of August 5-6, 2002 and August 23-24, 2006 are provided in Figures 17 and 18. The August 5-6, 2002 scenario predictions of 24-hr average and minimum DO concentrations were over 2 mg/L lower than the measured data, whereas the August 23-24, 2006 simulated DO concentrations were much more closely aligned with the measured data, though slightly higher. These two scenarios were delegated to the validation period because of the general lack of measured nutrient data forms for making model adjustments during the calibration step.

Because of the limited data for model calibration and validation, the scenarios of the calibration and validation were collectively analyzed in the next report section to give a more complete understanding of the performance of the QUAL2K model of Urban Brady Creek.

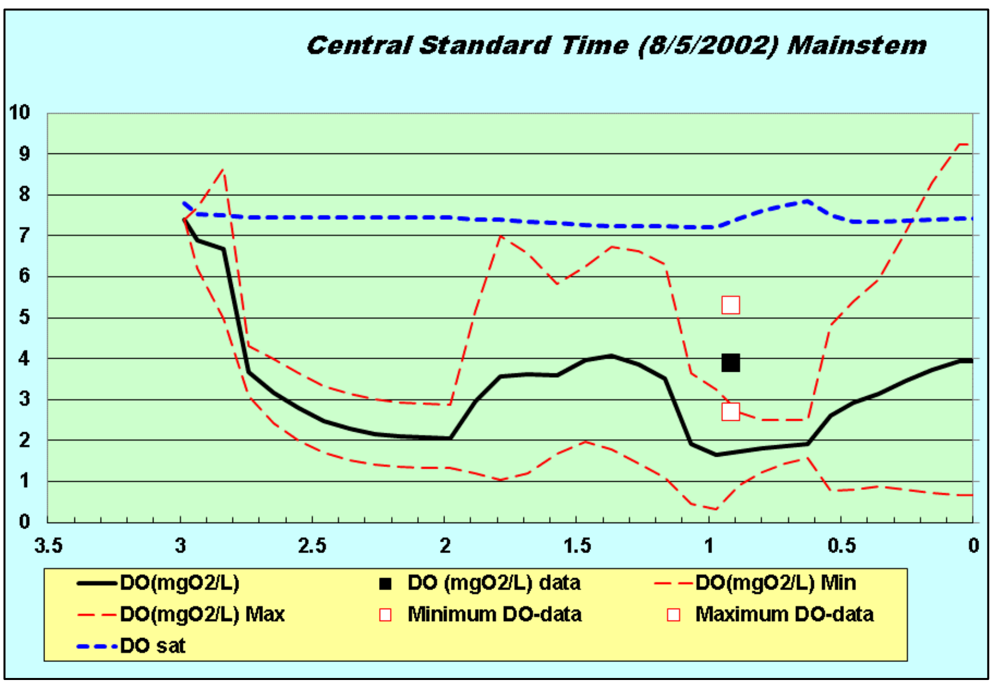


Figure 17 **Validation results for QUAL2K for 4-5 August 2002**
Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L

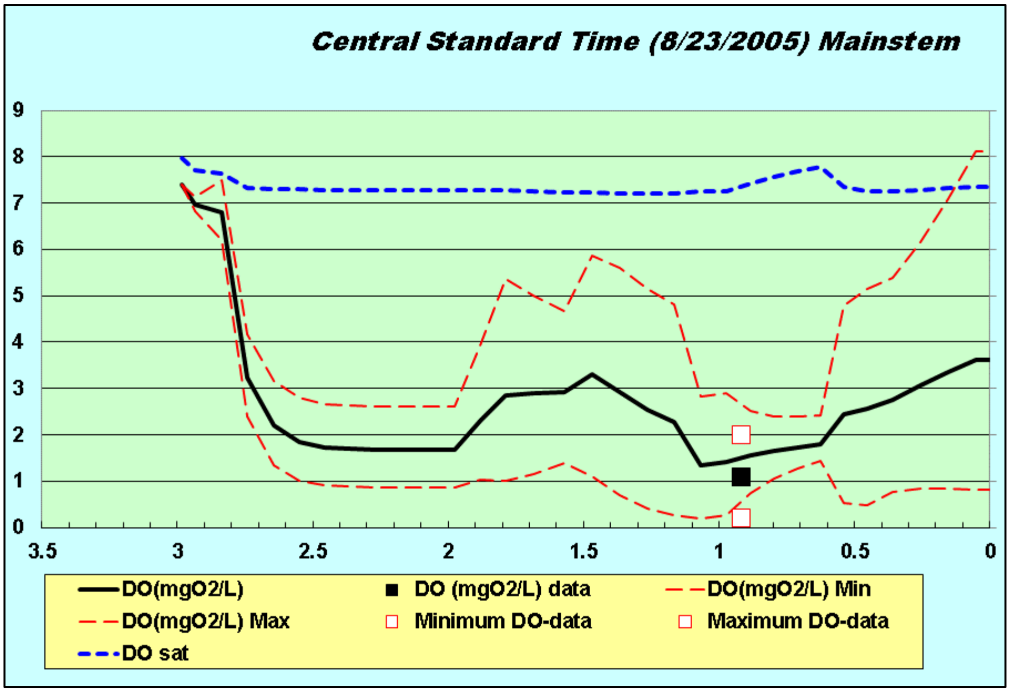


Figure 18 Validation results for QUAL2K for 22-23 August 2005
Note: x-axis is distance in kilometers; y-axis is DO concentration in mg/L

7.2.3 Combined Model Calibration/Validation Analysis

A summary of the combined calibration and validation results comparing measured and predicted water quality parameters at Station 17005 are provided in Table 4. The standard deviation of model predictions were always less than the standard deviation of measured values, indicating that natural variability was greater than simulated variability, but also reflecting that the water quality samples were collected three to four weeks prior to or after the 24-hr multiprobe deployments that were simulated. For the inorganic nutrient forms, the model predicted concentrations were very low, which was a response to the high phytoplankton population measured as CHLA found in both predicted and measured concentrations and the simulated update of nutrients to support that population. For TKN and TP, which included organic nutrient forms, the averages of model predictions were very close to the average of measured data. In all cases nutrients, TSS, and CHLA predictions were within two standard deviations of the mean of measured concentrations across all events, which was the goal to guide the verification process in the QAPP.

Predicted 24-hour average DO was on average 0.9 mg/L less than measured concentrations, and predicted 24-hour minimum DO was on average 0.6 mg/L less than measured concentrations. Both of these differences were well within the verification goals of 1.5 mg/L for 24-hour average DO and 2.0 mg/L for 24-hr minimum DO.

In conclusion, the QUAL2K model of Urban Brady Creek was considered acceptably calibrated and validated based on available water quality measurements for station 17005, which included six different 24-hr events. Model predictions of the critical parameters of 24-hour average and minimum DO are conservatively low, but well within the goal set for the model application.

Table 4 Summary comparison of measured and predicted values at TCEQ station 17005 for the combined calibration and validation scenarios

Parameter	WQ Stream Standard	Predicted Average concentration	Standard deviation of predicted concentrations	Measured average concentration	Standard deviation of measured concentrations
24-hr avg. DO (mg/L)	4.0	3.4	2.0	4.3	1.9
24-hr min. DO (mg/L)	3.0	2.2	1.9	2.8	2.7
NH_3-N (µg/L)	1950*	55	43	70	132
NO_{23}-N (µg/L)	1950*	8	8	126	294
TKN (µg/L)	1950*	1620	401	1763	1132
PO_4-P (µg/L)		1	1	105	95
TP (µg/L)	690*	163	30	185	123
CHLA (µg/L)	14.10*	109	13	105	95
TSS (mg/L)	NA	29	7	38	30

Notes: Units of parameters the same as those used in QUAL2K. In the computations for measured data, a value of ½ the reporting limit was used for concentrations reported as less than.

*Nutrient Screening Levels (From the 2014 Texas Integrated Report)

7.3 QUAL2K MODEL SENSITIVITY ANALYSIS

A sensitivity analysis was performed to investigate the impact of several input parameters on 24-hour average and minimum DO concentrations of Urban Brady Creek. The parameters selected for sensitivity analysis were phytoplankton maximum growth rate, reaeration rate, headwater flow, prescribed SOD rate, and CBOD decay rate. The sensitivity analysis used the September 18-19, 2006 calibration scenario as a baseline and altered one parameter at a time. Alterations of either +/- 25 percent or +/- 50 percent were applied to all the selected parameters based on confidence in the prescribed model input. A summary of results from the sensitivity analysis are provided in Table 6 for 24-hour average DO and Table 7 for 24-hour minimum DO in the modeling report in Appendix B

This sensitivity analysis yielded two conclusions. First, several parameters for which there were inadequate data for accurate characterization for the Urban Brady Creek had significant impacts on the model predictions of 24-hour average and minimum DO. Perhaps the most notable of these was the prescribed SOD rate reflecting stormwater contributions. As with all complex mechanistic water quality models, QUAL2K is over parameterized indicating uncertainty exists that the correct input parameters were adjusted in the verification process. That limitation stated, it is most encouraging that the critical average and minimum DO model outputs were overall adequately simulated in the calibration and validation steps, providing a level of confidence in the acceptability of the Urban Brady Creek QUAL2K model and an indication of robustness in model performance.

Second, the sensitivity of the DO to flow and prescribed SOD portend the potential efficacy of certain BMPs to decrease the occurrences of depressed DO along the Urban Brady Creek.

7.4 CONCLUSIONS ON QUAL2K MODEL VERIFICATION PROCESS

The QUAL2K representation of the Urban Brady Creek was subjected to a verification process that included separate calibration and validation steps using measured data from the period of 2002 through 2007, the period of time when 24-hour data were collected in this creek system. This process involved six different scenarios representing largely warm-season conditions of the Urban Brady Creek, which reflect the time of year when depressed DO is most likely to occur. The primary parameters predicted of concern was 24-hour average and minimum DO, because existing depressed DO issues in the creek are a result of non-support of the 4.0 mg/L 24-hour average DO criterion and 3.0 mg/L 24-hour minimum DO criterion assigned to Segment 1416A_03. Based on a combination of visual inspection and basic statistical analysis of measured and predicted DO and other water quality parameters, the QUAL2K model was found to satisfactorily predict the primary parameters of 24-hour average and minimum DO. The model generally underestimated DO concentrations, thus affording a built-in margin of safety into analyses presented in the subsequent chapter where BMPs to restore water quality and reduce occurrences of depressed DO are discussed.

7.5 QUAL2K MODEL EVALUATION OF MANAGEMENT OPTIONS FOR DISSOLVED OXYGEN IMPROVEMENT IN URBAN BRADY CREEK

The environmental goals for DO in Urban Brady Creek (lower portion of AU 1416A_03) are based on an assumed intermediate aquatic life use designation. One water quality constituent considered to protect the intermittent aquatic life use is DO. To be considered supportive of intermediate aquatic life use, DO values must meet or exceed the following two criteria, a 24-hour average DO of at least 4.0 mg/L and a 24-hour minimum DO of at least 3.0 mg/L.

These criteria are not being supported when 10 percent or more of the data do not attain to each of these criteria (TCEQ, 2010b).

Pursuant to achievement of this goal, the calibrated and validated QUAL2K model of Urban Brady Creek was used to evaluate selected best management practices (BMPs) to determine their individual and collective efficacy in restoring DO levels in this reach of Brady Creek. The evaluation approach used QUAL2K model runs to evaluate existing (baseline) conditions and to predict conditions if various management options are implemented. Two management options were considered in the modeling process: a reduction in urban stormwater pollution from the installation of structural controls, and baseflow enhancement sourced by the City of Brady's WWTF.

The control measure evaluation approach employed the following steps to evaluate each management option:

1) Operate QUAL2K for the selected conditions without any management options, but above (baseline conditions) to predict DO concentrations and extract from model output the 24-hour average and minimum DO predictions at desired locations,
2) Operate QUAL2K to predict DO for each management option and extract from model output the 24-hour average and minimum DO predictions at desired locations, and
3) Develop DO duration curves based on model predicted values at desired locations, and then compare results to the relevant environmental goal of no more than 10 percent of the data being less than the relevant average and minimum DO criteria.

Step 1 – Operate QUAL2K for Baseline Scenarios

The QUAL2K model of each of the 24 scenarios listed in Table 5 was run to provide the baseline conditions of 24-hour average and minimum DO values for Urban Brady Creek at

1) the pier above the Elm Street low-water crossing and
2) for the entire reach simulated (defined as Urban Brady Creek).

From model output, two sets of pairs of average and minimum DO predictions was extracted; one set for the pier location and the other for the entire reach. Since the pier location at a unique point in the model, the average and minimum 24-hour DO values predicted by the model at that point were extracted from model output. For Urban Brady Creek, the minimum 24-hour average DO concentration and the minimum 24-hour minimum DO concentration was selected from the entirety of the reach. Within Urban Brady Creek, these minimums occurred at different locations dependent upon model input conditions for each of the 24 scenarios.

One QUAL2K scenario was developed for each month of the years 2005 and 2006, which were the years when most of the historical 24-hour DO data were collected (five of seven measurements). By selecting each month for two consecutive years, a reasonable representation of the annual range of environmental conditions encountered was obtained. The date selected for simulation in each month was when streamflow was relatively steady or, in many instances, at zero with an additional preference given to a date in the middle of each month. Similar to the calibration and validation process, whenever the USGS gage indicated zero flow, the headwater base flow was set in the QUAL2K input to 0.05 cfs, since the model requires some minimum flow to operate. The required QUAL2K input of hourly weather data (i.e., air and dew point temperatures, wind speed, and cloud cover) were obtained from the San Angelo Regional Airport; the nearest weather station reporting hourly data. During the operation of QUAL2K for the baseline conditions wind speeds were often reduced to reflect the wind sheltering along the creek as was found necessary in the model calibration and validation process to replicate measured temperatures.

Table 5 QUAL2K scenarios used in evaluation of management options

Scenario No.	Year 2005 (month, day and assigned baseflow)	Scenario No.	Year 2006 (month, day and assigned baseflow)

1	January 11; 0.27 cfs	13	January 15; 0.05 cfs
2	February 17; 0.21 cfs	14	February 15; 0.05 cfs
3	March 14; 0.18 cfs	15	March 15; 0.05 cfs
4	April 17; 0.21 cfs	16	April 15; 0.05 cfs
5	May 18; 0.09 cfs	17	May 15; 0.05 cfs
6	June 15, 0.05 cfs	18	June 15; 0.05 cfs
7	July 12; 0.05 cfs	19	July 15; 0.05 cfs
8	August 22; 0.07 cfs	20	August 15; 0.05 cfs
9	September 13; 0.05 cfs	21	September 15; 0.05 cfs
10	October 8; 0.05 cfs	22	October 8; 0.05 cfs
11	November 15; 0.05 cfs	23	November 16; 0.05 cfs
12	December 15; 0.05 cfs	24	December 15; 0.05 cfs

Step 2 – Operate QUAL2K for Each of 7 Management Options

To evaluate each selected management option, each of the 24 QUAL2K monthly scenarios was run with model input changed to reflect the change in environmental conditions imposed by the control measure(s) comprising the management option. Similar to Step 1, for each run the required pair of average and minimum DO predictions for the pier location and the overall reach of Urban Brady Creek were extracted from the model output.

The control measures considered for evaluation and the associated management option number are discussed immediately below.

Option 1 – 25 Percent Reduction in Sediment Oxygen Demand/Nutrient Fluxes
Under Option 1, SOD and nutrient fluxes at the sediment-water interface were reduced 25 percent reflecting efficacy of urban stormwater controls. Urban stormwater controls are discussed in Section 8 herein.

The QUAL2K model of Urban Brady Creek, as developed in the calibration and validation process, had a user prescribed SOD and sediment nutrient flux terms as well as the SOD and sediment nutrient fluxes determined from a submodel within QUAL2K. The submodel determines SOD and nutrient fluxes as a function of settling of particulate organic matter, reactions within the sediments, and the concentration of soluble forms of nutrients in the overlying water. Thus the submodel predicts the SOD and nutrient fluxes from the present water quality conditions being simulated, which are baseflow. The submodel, however, does not include additional sources of SOD and nutrient fluxes from organic matter deposited from such processes as stormwater runoff. The user prescribed SOD and nutrient fluxes were applied during the calibration and validation process to reflect this additional source.

It is the user prescribed SOD and nutrient fluxes that were reduced to account for the benefits of urban stormwater controls, and the submodel predictions were left to be computed within QUAL2K to reflect the baseflow conditions being simulated.

Option 2 – 50 Percent Reduction in Sediment Oxygen Demand/Nutrient Fluxes
Under Option 2, stormwater-related SOD and nutrient fluxes at the sediment-water interface were reduced 50 percent reflecting efficacy of urban stormwater controls. As with Option 1, the QUAL2K submodel was left on to account for SOD and nutrient fluxes from the settled particulate matter associated with the scenario.

Option 3 – Pump Wastewater Effluent
Under Option 3, all the City of Brady WWTF effluent was pumped to above the eastside pool in Richards Park. The effluent was pumped for the months of April – October and for each of the remaining months the baseline results for that month were used. It is unnecessary to pump the effluent during November – March, because under normal flow conditions the model indicates Urban Brady Creek achieves the applicable DO criteria when water temperatures are low, oxygen saturation is higher, and biological processes are slowed due to the lower temperatures.

The characteristics of the WWTF effluent were based on Discharge Monitoring Report data for the period July 2009 through June 2012 as obtained from the USEPA Enforcement & Compliance History Online (ECHO) accessed February 16, 2012. The discharge rate used of 0.27 million gallons per day (MGD) represented the flow exceeded 90 percent of the time, which was considered a reasonable low flow estimate. The reported median concentrations for BOD and NH_3-N were used. For water quality parameters not monitored, TCEQ guidance for default values in QUAL-TX when performing waste load evaluations was used for nitrogen forms and the phosphorus was based on small WWTF monitoring performed in the North Bosque River (TIAER, 2006). A small amount of phytoplankton was also assumed present at a concentration of 2 µg/L. The assumed discharge and water quality characteristics are provided in Table 6.

Table 6 Characteristic of Pumped Effluent from City of Brady WWTF

Parameter	Value
Flow (MGD)	0.27
Inorganic Solids (µg/L)	5.00
Dissolved Oxygen	6.00
CBOD fast	6.40
Organic Nitrogen (µg/L)	2000
NH4-Nitrogen (µg/L)	200
NO3-Nitrogen (µg/L)	17800
Organic Phosphorus (µg/L)	900
Inorganic Phosphorus (SRP) (µg/L)	3200
Phytoplankton (µg/L)	2.00
Detritus (POM)	3.40

Option 4 – Combination of Options 2 & 3
Option 4 combines pumping of the effluent from the City of Brady WWTF (Option 3) with stormwater strategies that reduced SOD/nutrient fluxes by 50 percent. The WWTF effluent was characterized in QUAL2K as presented in Table 6. The effluent was pumped for the months of April – October and for each of the remaining months, the Option 2 results (50% SOD and nutrient fluxes reduction) for those months were used.

Option 5 – Pumped Wastewater Effluent Discharged Through Diffuser
Option 5 is similar to Option 3 except the pumped effluent is discharge through a diffuser into the eastside pool of Richards Park. The WWTF effluent was characterized in QUAL2K as presented in Table 6. The effluent was pumped for the months of April – October and for each of the remaining months the baseline results for that month were used.

The diffuser option of discharging the pumped effluent was implemented to reduce the impacts of the direct discharge immediately above the pool by dispersing the effluent uniformly along the most upstream 0.5 km of the pool.

Option 6 – Combination of Options 1 and 5
Options 6 combines pumping of the effluent from the City of Brady WWTF and discharging the pumped effluent through a diffuser into the eastside pool of Richards Park (Option 5), with stormwater strategies that reduced SOD/nutrient fluxes by 25 percent (Option 1). The WWTF effluent was characterized in QUAL2K as presented in Table 6. The effluent was pumped for the months of April – October and for each of the remaining months the Option 1 (25% SOD and nutrient fluxes reduction) results for those months were used.

Option 7 – Combination of Options 2 and 5
Option 7 combines pumping of the effluent from the City of Brady WWTF and discharging the pumped effluent through a diffuser into the eastside pool of Richards Park (Option 5) with stormwater strategies that reduced SOD and nutrient fluxes by 50 percent (Option 2). The WWTF effluent was characterized in QUAL2K as presented in Table 6. The effluent was pumped for the months of April – October and for each of the remaining months the Option 2 (50% SOD/nutrient flux reduction) results for those months were used.

Step 3 – Develop DO Duration Curves for Each of 7 Management Options

As the final step in the evaluation of management options DO duration curves were developed to indicate the percentage of the time that average and minimum DO concentrations support (exceed) the appropriate numeric criterion considering the following:

1) the pier above the Elm Street low-water crossing and
2) for the entire reach simulated (Urban Brady Creek).

Separate duration curves were developed by processing model output for the baseline condition and for each of the 7 management options. The processing occurred separately for the 24-hour average and minimum datasets for both the pier location and the entire simulated reach. The process entails the following:

1) Considering each of the two locations separately, the DO data extracted from the 24 monthly QUAL2K simulations were organized into two unique datasets; one each for the 24-hour minimum DO data and the 24-hour average DO data. This organization is repeated for the baseline condition and each of the 7 management options.
2) Rank the extracted values in each dataset from highest DO value to lowest value for the 24 data points comprising the dataset giving each value a rank n that ranges from 1 (highest) to 24 (lowest).
3) Determine the percent of the time that each value is exceeded by dividing the rank n by the number of values plus one (24 + 1 = 25) and multiply by 100 to get into percent.
4) Plot the 24 pairs of DO values and exceedance values with the x-axis as exceedance and the y-axis as the DO value forming a DO duration curve.
5) The DO criterion intersection of the exceedance line provides the percent of time the DO criterion is met. 4.0 mg/L was used as the criterion for 24-hour average DO and 3.0 mg/L for the minimum DO.

7.5.1 Evaluation of Each of 7 Management Options With QUAL2K

Following the approach outlined above, the baseline condition was run for each of the 24 monthly QUAL2K scenarios and then each of the management options were run for the 24 scenarios changing the input to QUAL2K as needed to reflect the conditions of that management option. Dissolved oxygen duration curves were developed for the baseline condition and for each management option, including separate curves for 24-hour average and minimum DO at each of the two locations (pier above Elm Street and the entirety of Urban Brady Creek). For comparison purposes the baseline exceedance curves are included with the exceedance curves for each management option in a series of 14 figures with each figure containing two graphs - [A] the 24-hour average DO and [B] the 24-hour minimum DO. There will be two figures per management option; one representing the pier location and the other representing the minimum for the entire length of Urban Brady Creek.

Throughout the remainder of this section, each management option is briefly discussed followed by its DO exceedance curves. A summary of the results of all 7 management options is provided in Table 7 at the end of this section of the WPP.

Option 1 considered a 25 percent reduction in the SOD and nutrient fluxes from the sediment that were assigned to stormwater loadings. These reductions would need to be achieved through placement of stormwater BMPs in key areas of the City of Brady. The DO curves of the baseline condition and Management Option 1 are provided in two graphics – Figure 19 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 20 for the minimum concentrations occurring along the entire length of Urban Brady Creek. This option resulted in only small improvement in the amount of time the 24-hr minimum and average DO criteria were obtained.

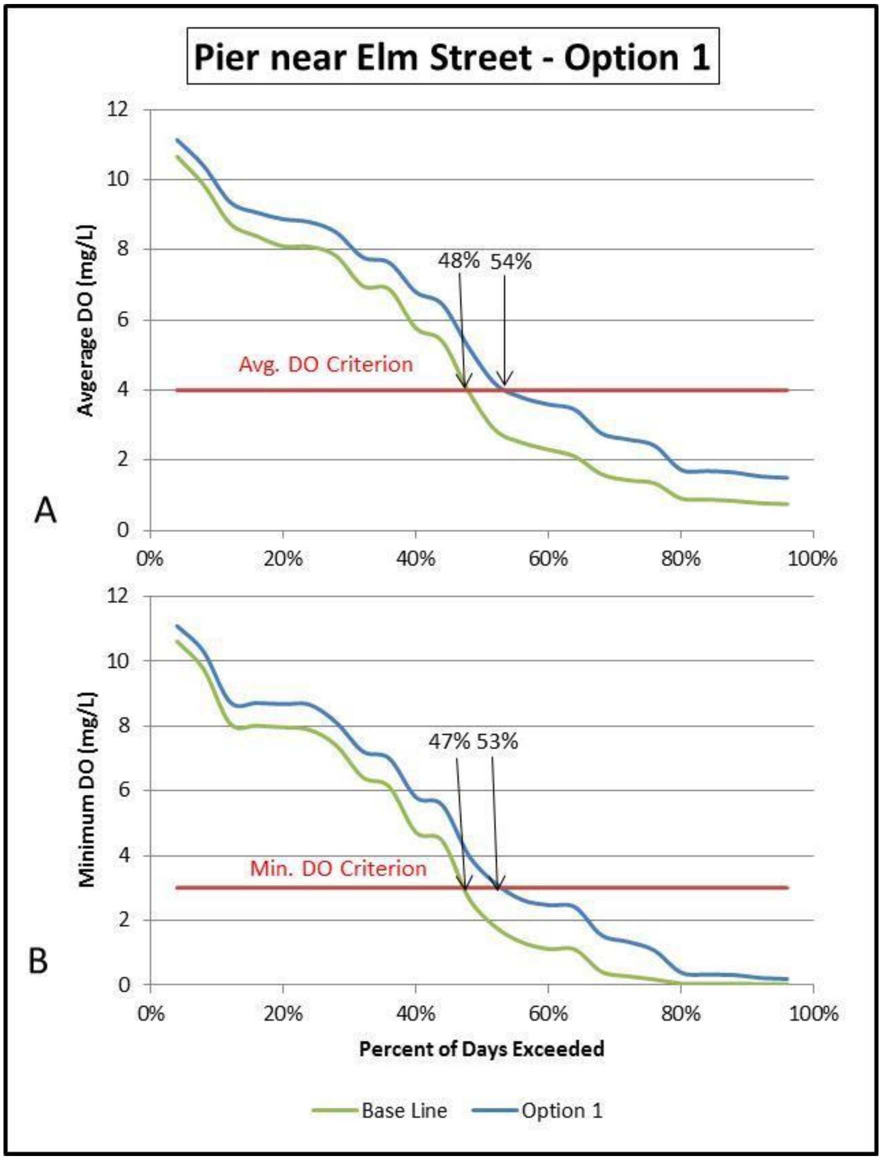


Figure 19 **Dissolved oxygen duration curves for baseline condition and Management Option 1 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

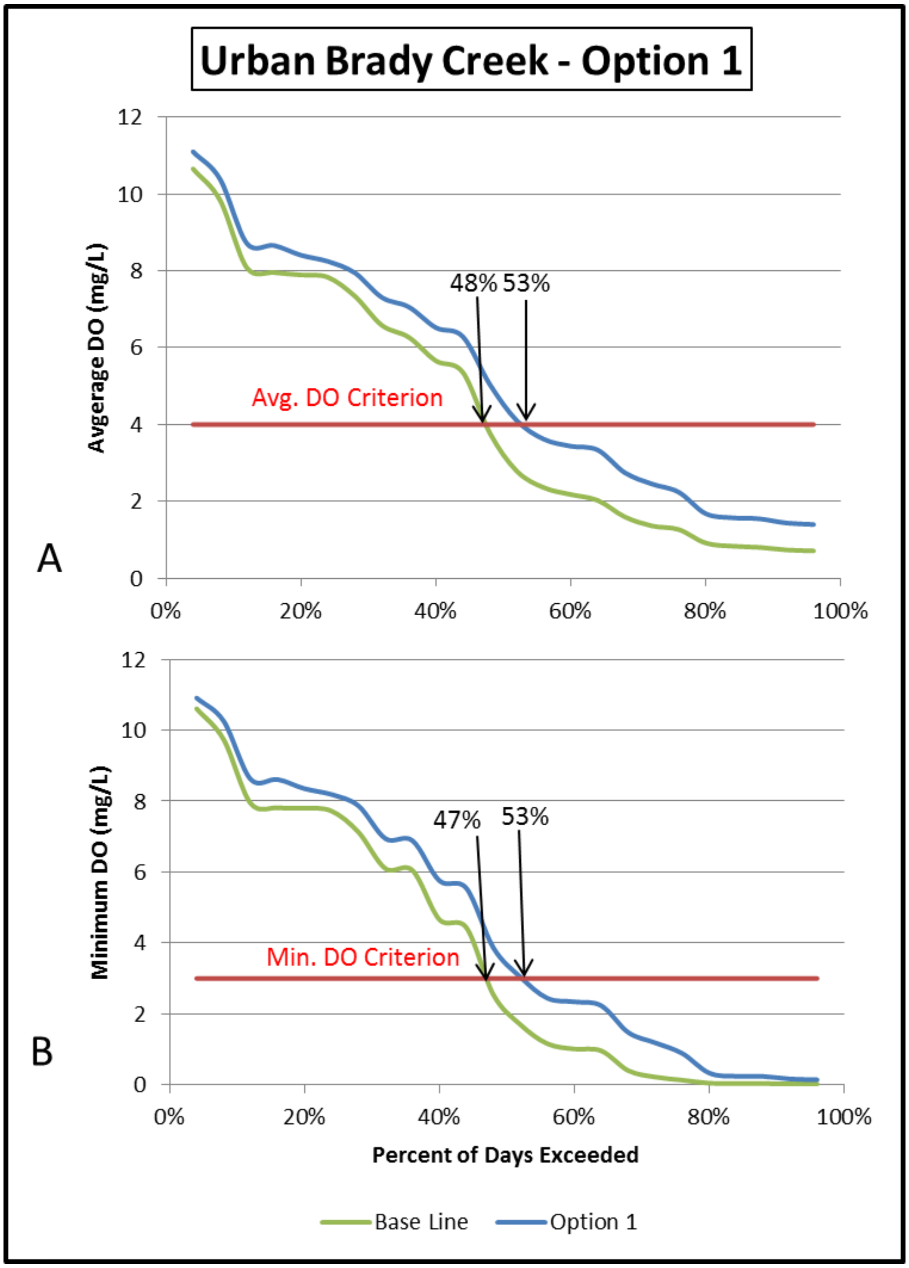


Figure 20 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 1 (monthly scenarios for 2005 & 2006)**

Option 2 considered a 50 percent reduction in the SOD and nutrient fluxes from the sediment that were assigned to stormwater loadings. These reductions would need to be achieved through placement of stormwater BMPs in key areas of the City of Brady. The DO curves of the baseline condition and Management Option 1 are provided in two graphics – Figure 21 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 22 for the minimum concentrations occurring along the entire length of Urban Brady Creek. This option resulted in the 24-hr minimum and average DO criteria being obtained about three quarters of the time, which represented appreciable improvement from the baseline but still falls short of the needed 90 percent attainment.

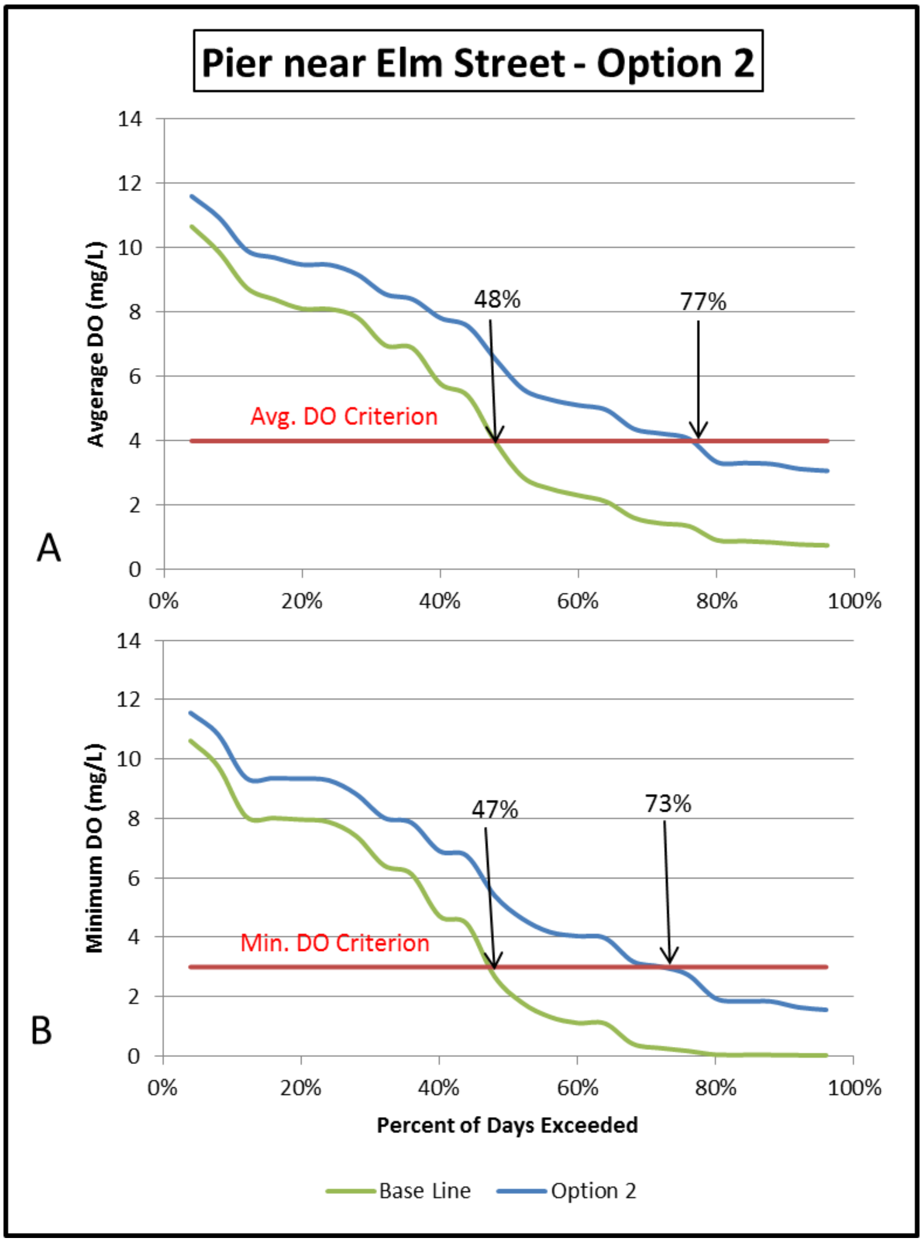


Figure 21 **Dissolved oxygen duration curves for baseline condition and Management Option 2 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

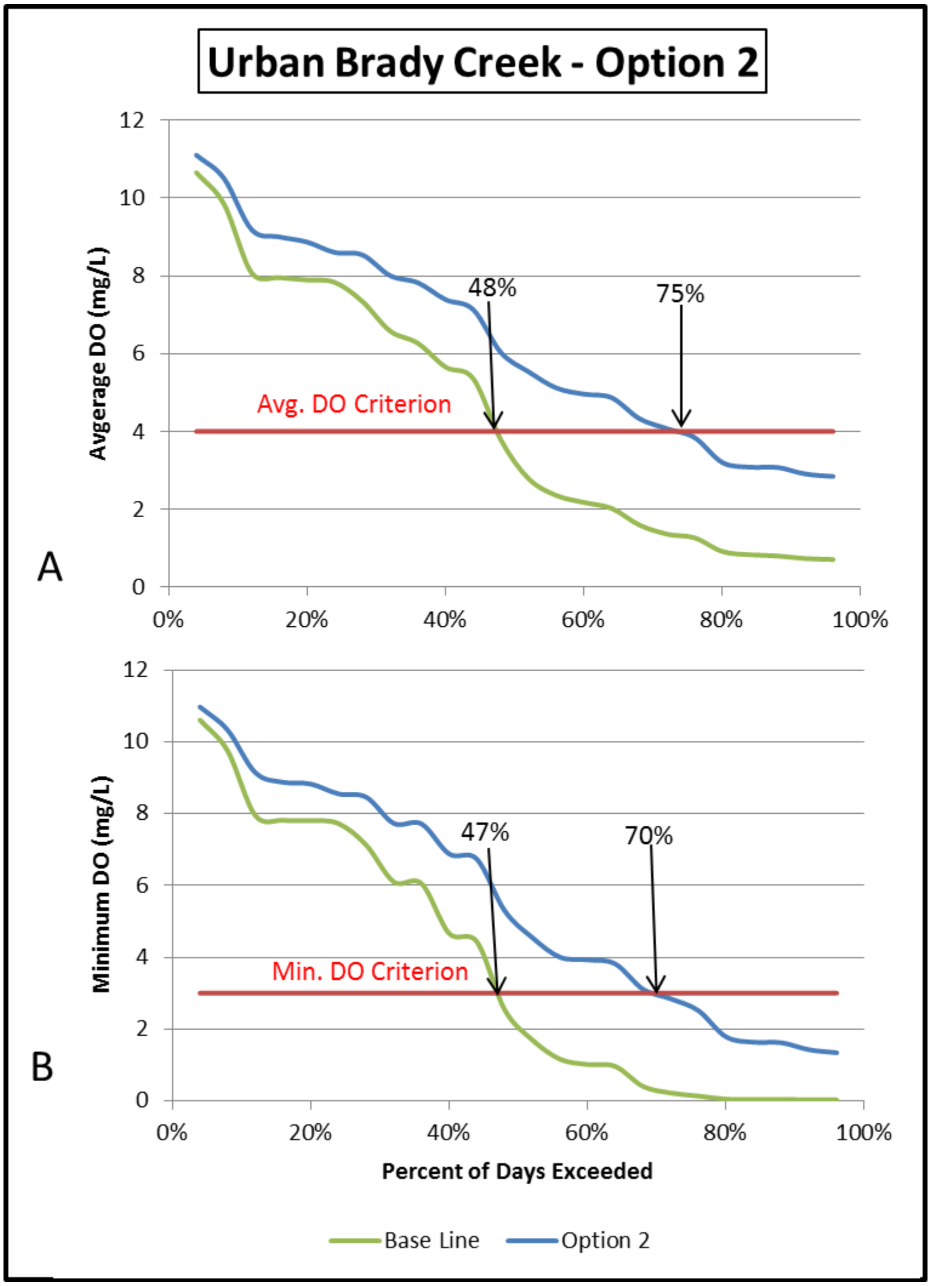


Figure 22 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 2 (monthly scenarios for 2005 & 2006)**

Option 3 considered pumping of the effluent from the City of Brady WWTF to a location upstream of the Richards Park "eastside" pool. The DO curves of the baseline condition and Management Option 3 are provided in two graphics – Figure 23 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 24 for the minimum concentrations occurring along the entire length of Urban Brady Creek. Option 3 results in the 24-hr minimum and average DO criteria being obtained about two-thirds of the time at the monitoring location at the pier in the pool above Elm Street. This option, however, did not provide much overall benefit when the entirety of Urban Brady Creek was considered because the benefits of the additional flow from the WWTF effluent were offset by the immediate impact of the effluent in the Richards Park "eastside" pool.

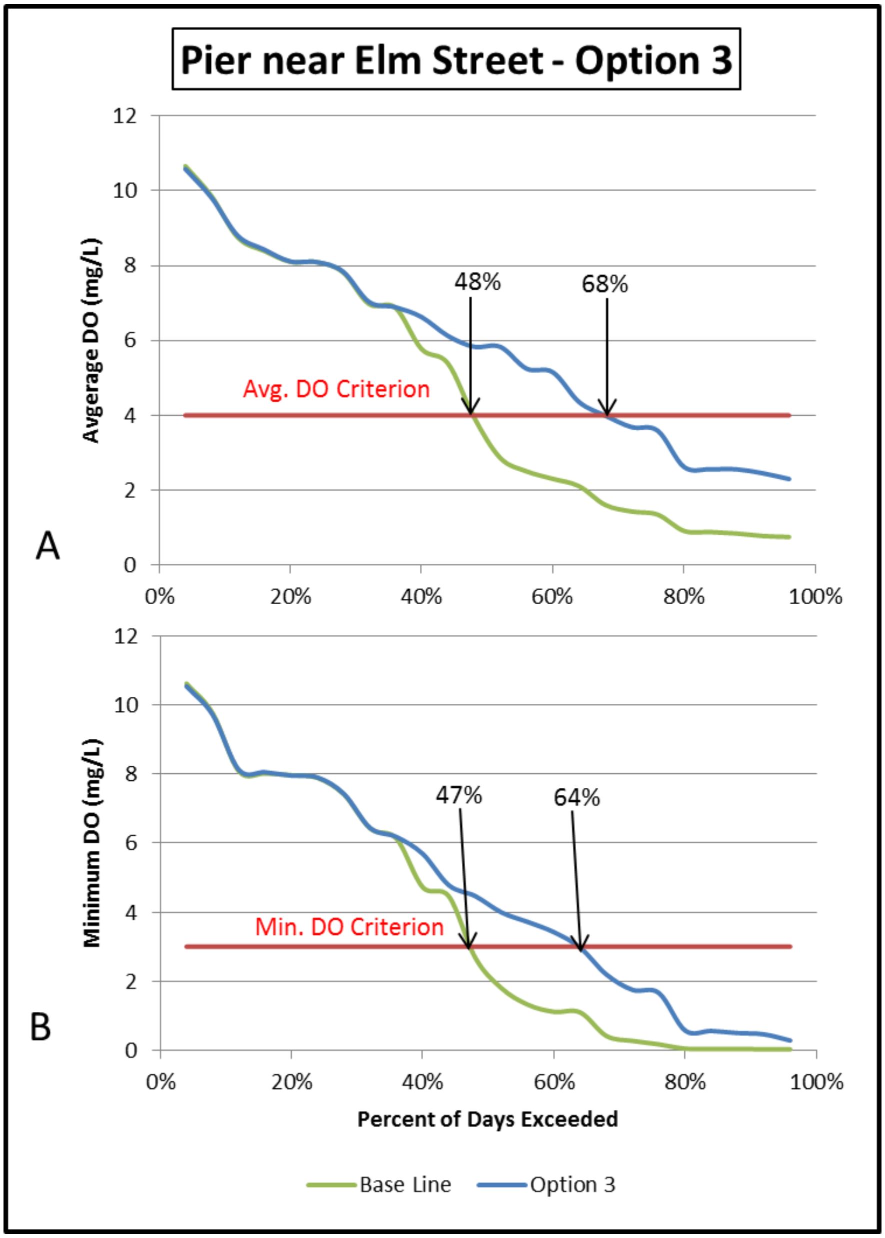


Figure 23 **Dissolved oxygen duration curves for baseline condition and Management Option 3 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

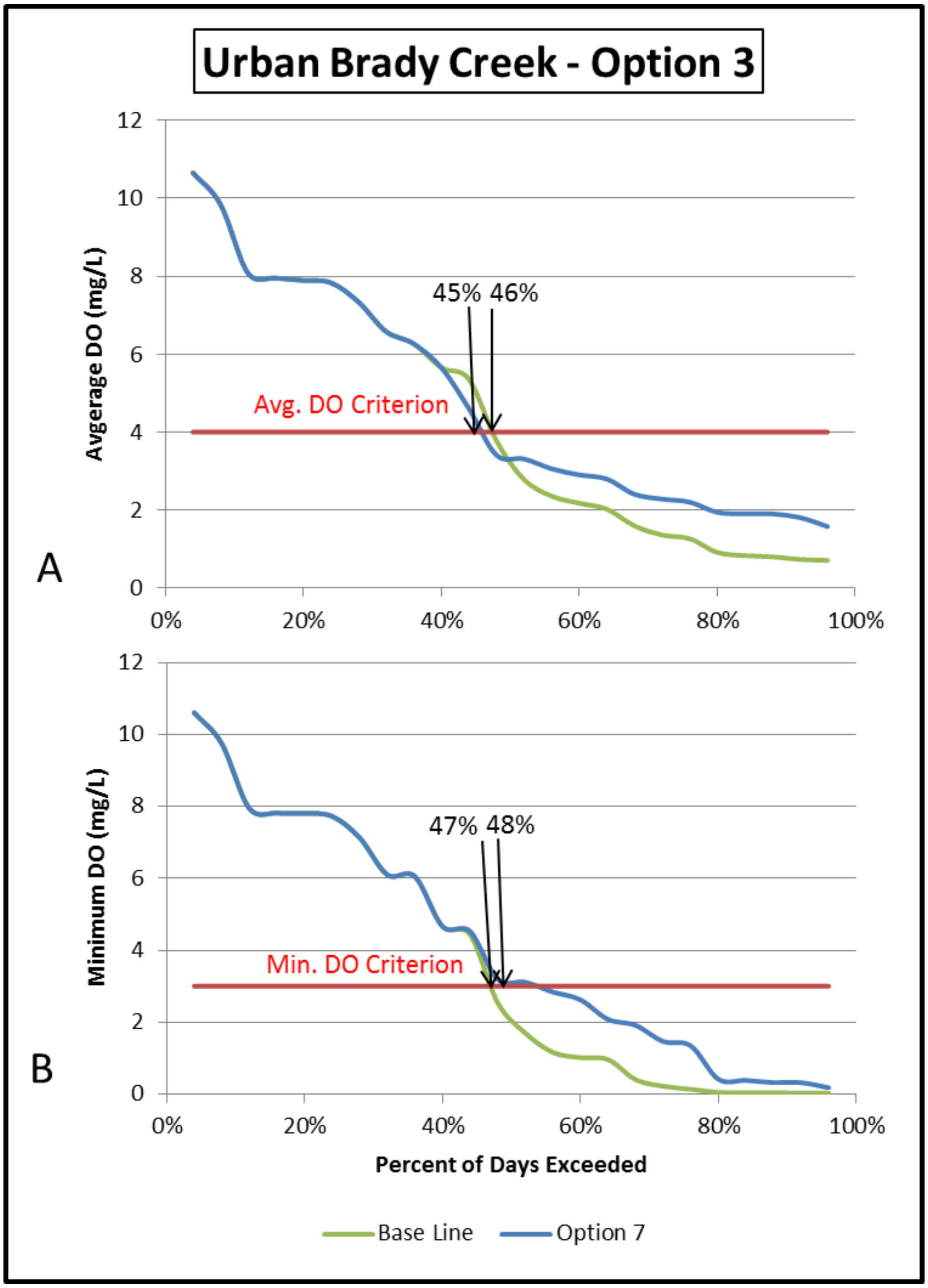


Figure 24 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 3 (monthly scenarios for 2005 & 2006)**

Option 4 combines the 50 percent reduction in stormwater-derived SOD and sediment nutrient fluxed (Management Option 2) and the pumping of the effluent from the City of Brady WWTF to a location upstream of the Richards Park "eastside" pool (Management Option 3). The DO curves of the baseline condition and Management Option 4 are provided in two graphics – Figure 25 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 26 for the minimum concentrations occurring along the entire length of Urban Brady Creek. Option 4 resulted in the 24-hr minimum and average DO criteria being obtained about 100 percent of the time at the monitoring location at the pier in the pool above Elm Street and at or just below 90 percent of the time for the entirety of Urban Brady Creek. While falling just short of meeting the 90 percent of the time for the 24-hr average DO, this may be considered within the uncertainty of model results and should be considered a viable alternative that may achieve the desired restoration of DO concentrations in the creek.

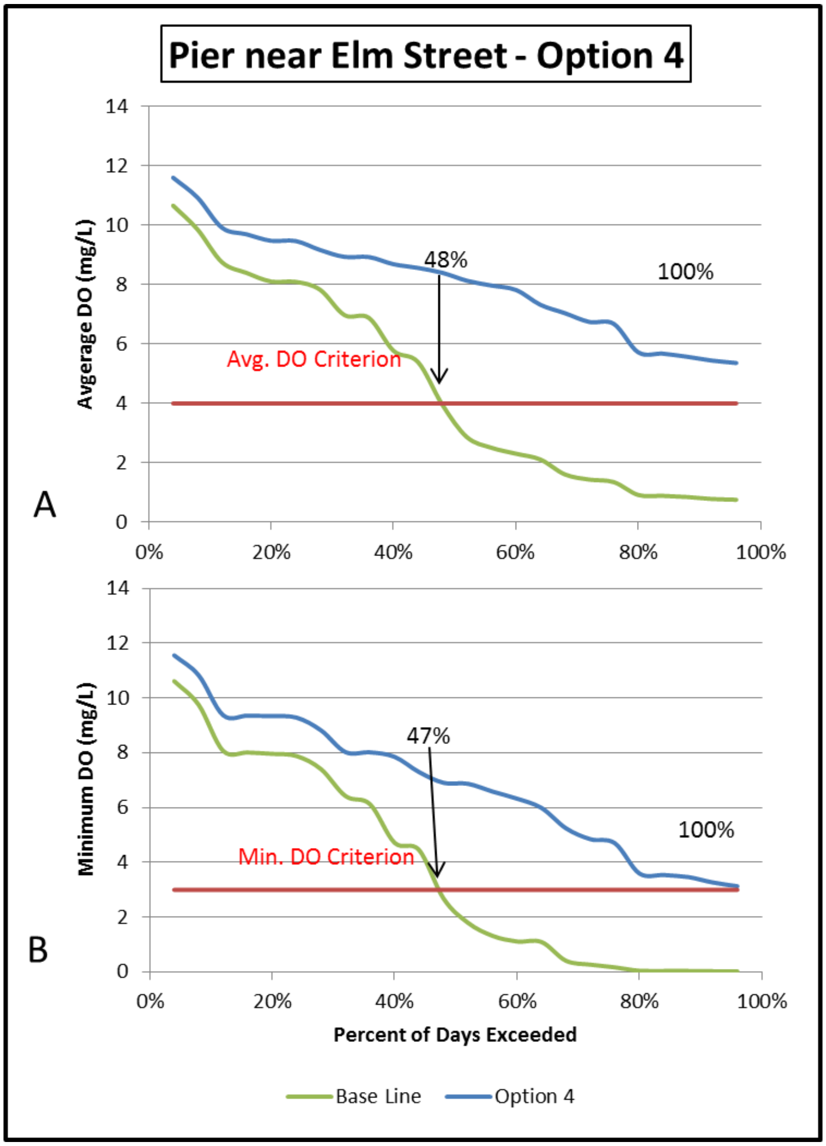


Figure 25 **Dissolved oxygen duration curves for baseline condition and Management Option 4 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

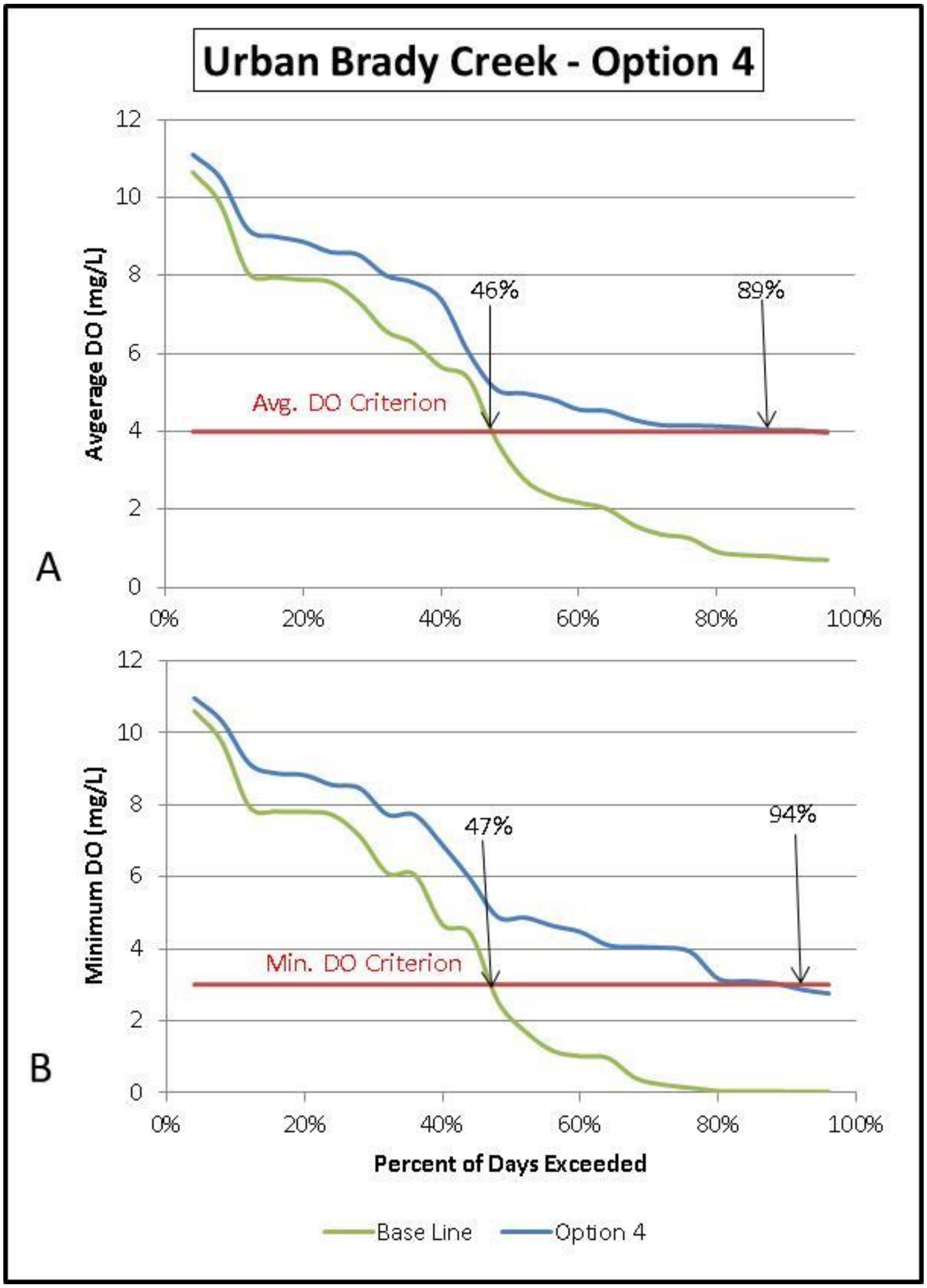


Figure 26 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 4 (monthly scenarios for 2005 & 2006)**

Option 5 considered pumping of the effluent from the City of Brady WWTF to the Richards Park "eastside" pool and the distribution of the effluent through a diffuser long the upper 0.5 km of the pool. The DO curves of the baseline condition and Management Option 5 are provided in two graphics – Figure 27 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 28 for the minimum concentrations occurring along the entire length of Urban Brady Creek. Option 5 resulted in the 24-hr minimum and average DO criteria being obtained about two-thirds to three-fourths of the time at the monitoring location at the pier in the pool above Elm Street. This option with the diffuser, however, did provide more overall benefit to the entirety of Urban Brady Creek than Management Option 3 without the diffuser, but there still remained enough immediate impact of the effluent in the Richards Park "eastside" pool that only moderate improvement was indicated.

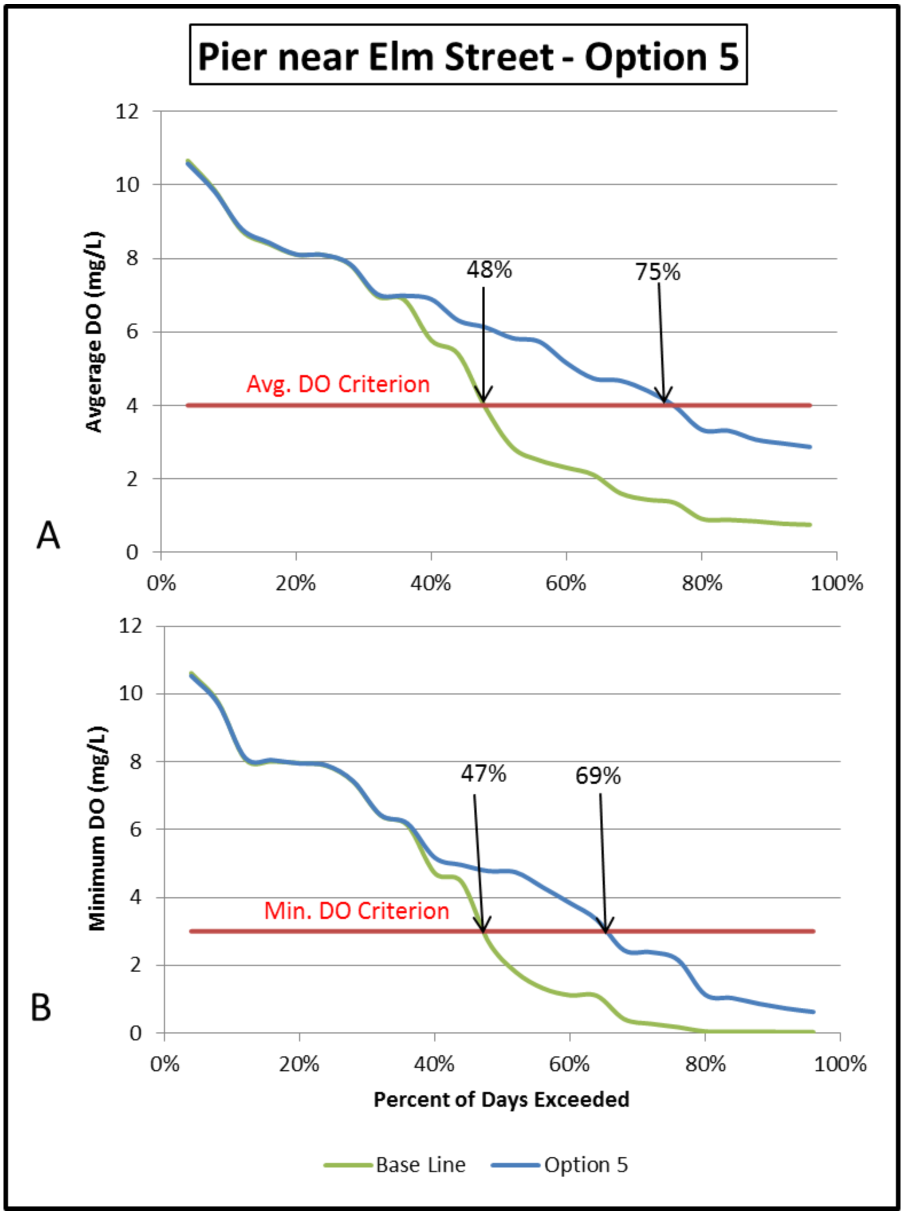


Figure 27 **Dissolved oxygen duration curves for baseline condition and Management Option 5 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

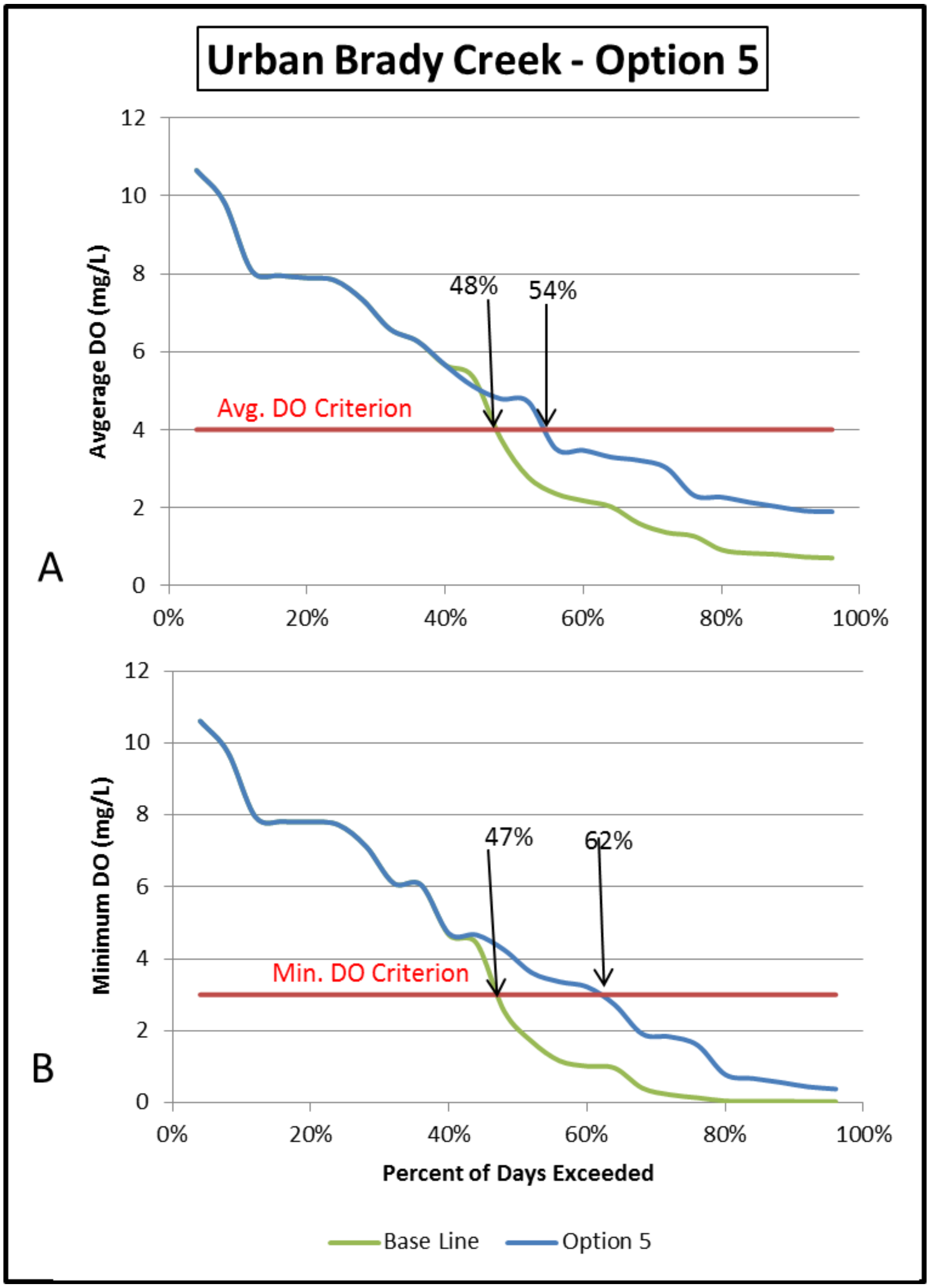


Figure 28 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 5 (monthly scenarios for 2005 & 2006)**

Option 6 combines a 25 percent reduction in stormwater-derived SOD and sediment nutrient fluxes (Management Option 1) and the pumping of the effluent from the City of Brady WWTF to the Richards Park "eastside" pool and the distribution of the effluent through a diffuser long the upper part of the pool (Management Option 5). The DO curves of the baseline condition and Management Option 5 are provided in two graphics – Figure 29 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 30 for the minimum concentrations occurring along the entire length of Urban Brady Creek. Option 6 provided significant improvement in the percentage of time that the 24-hr minimum and average DO criteria were met at both the pier locations and for the entirety of Urban Brady Creek. This option, however, did not of itself achieve the needed improvement to restore water quality.

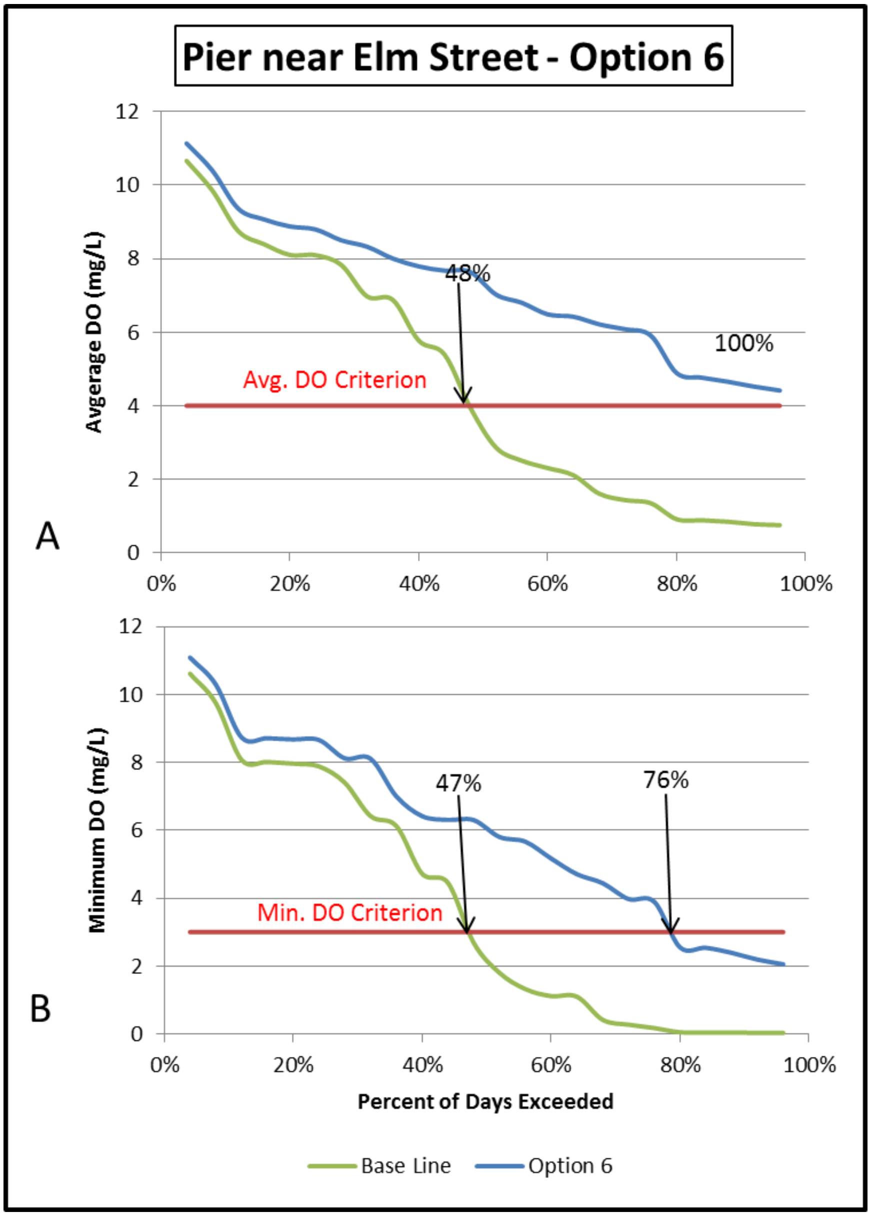


Figure 29 **Dissolved oxygen duration curves for baseline condition and Management Option 6 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

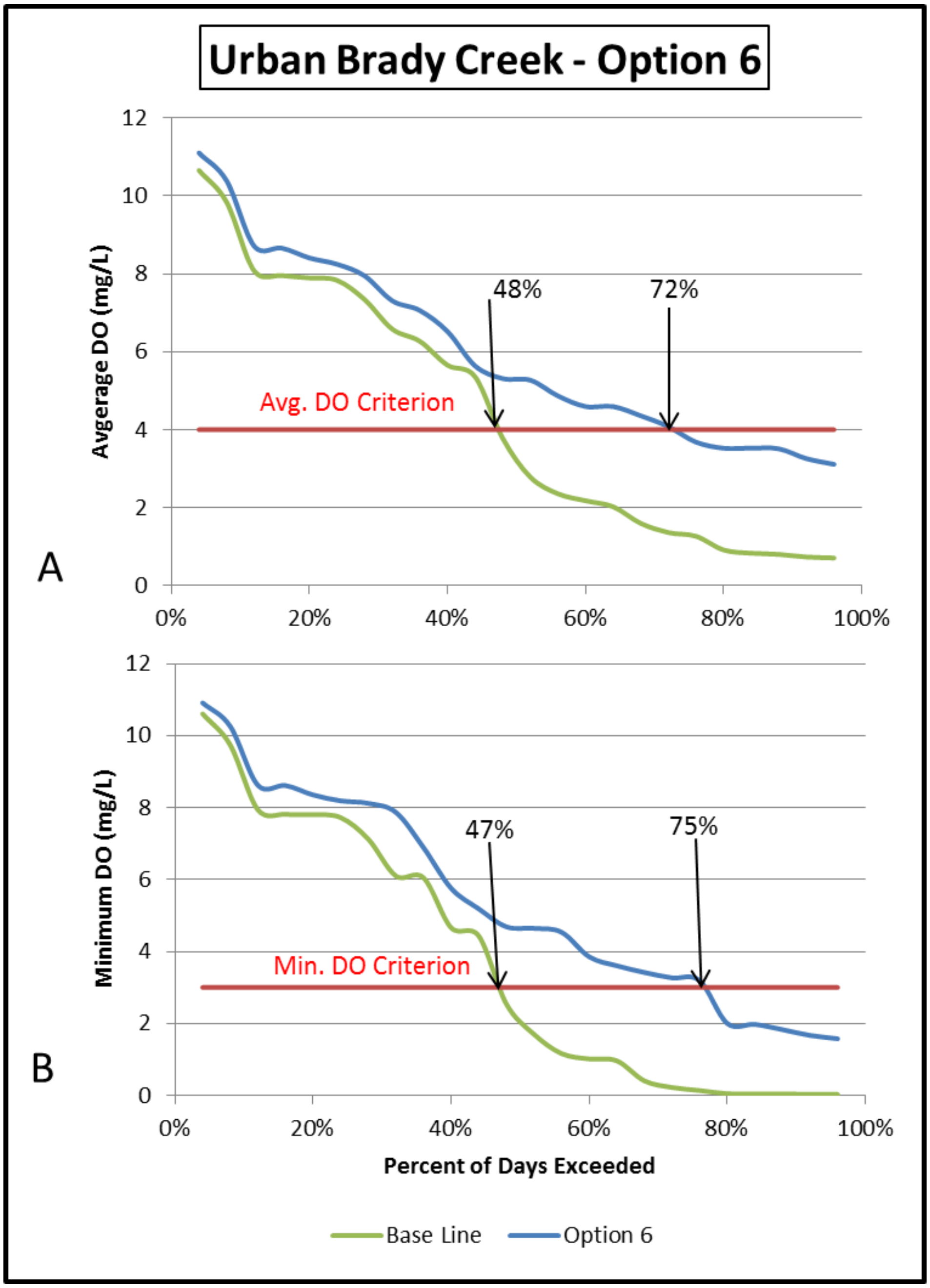


Figure 30 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 6 (monthly scenarios for 2005 & 2006)**

Option 7 combines a 50 percent reduction in stormwater-derived SOD and sediment nutrient fluxes (Management Option 2) and the pumping of the effluent from the City of Brady WWTF to the Richards Park "eastside" pool and the distribution of the effluent through a diffuser along the upper 0.5 km of the pool (Management Option 5). The DO curves of the baseline condition and Management Option 5 are provided in two graphics – Figure 31 for simulated concentrations at the pier in the pool above the Elm Street low-water crossing and Figure 32 for the minimum concentrations occurring along the entire length of Urban Brady Creek. The simulated conditions for Management Option 7 indicated that this option was the most likely to restore the DO concentrations to levels meeting the criteria for Brady Creek.

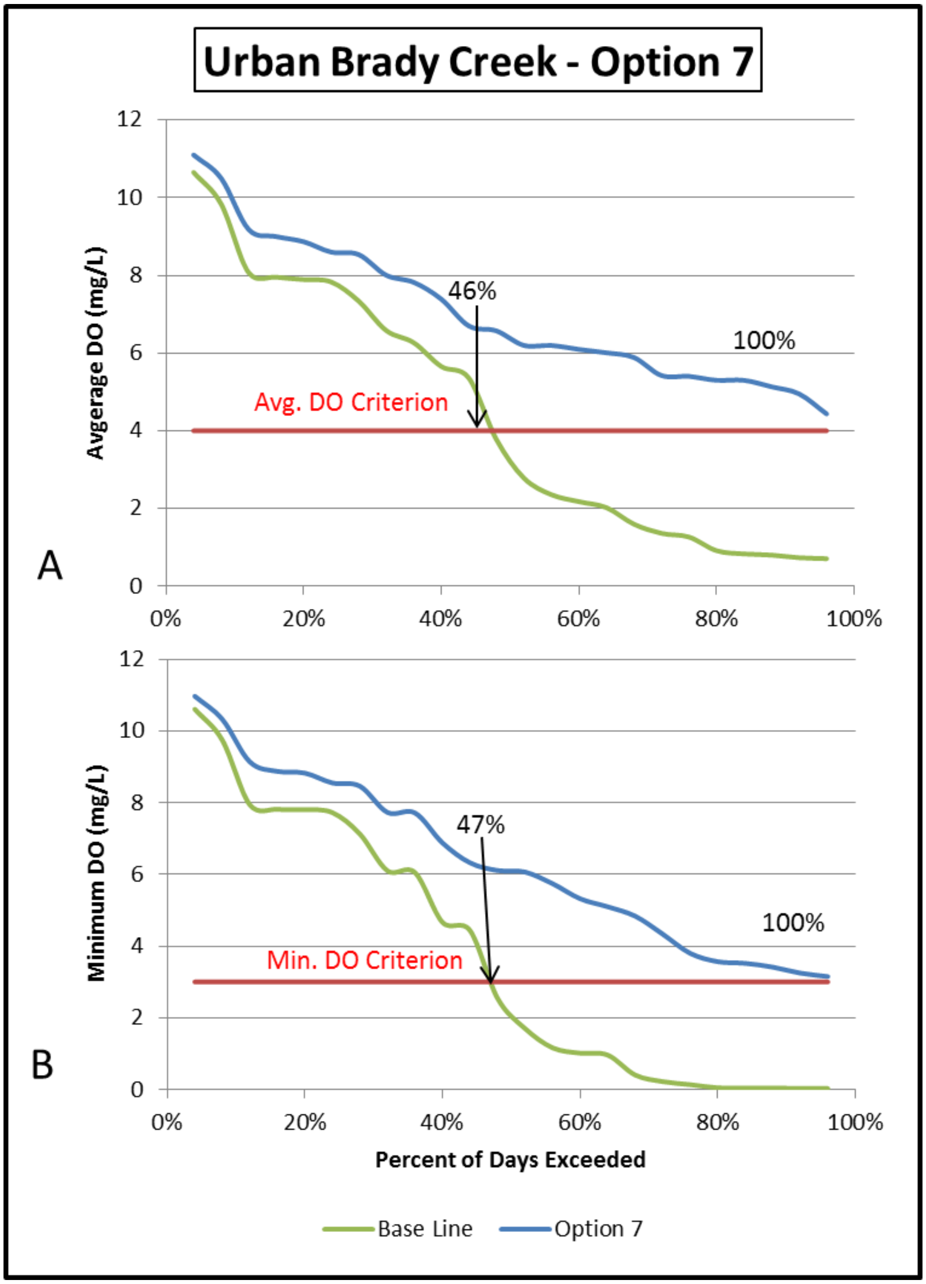


Figure 31 **Dissolved oxygen duration curves for baseline condition and Management Option 7 at the pier above Elm Street (monthly scenarios for 2005 & 2006)**

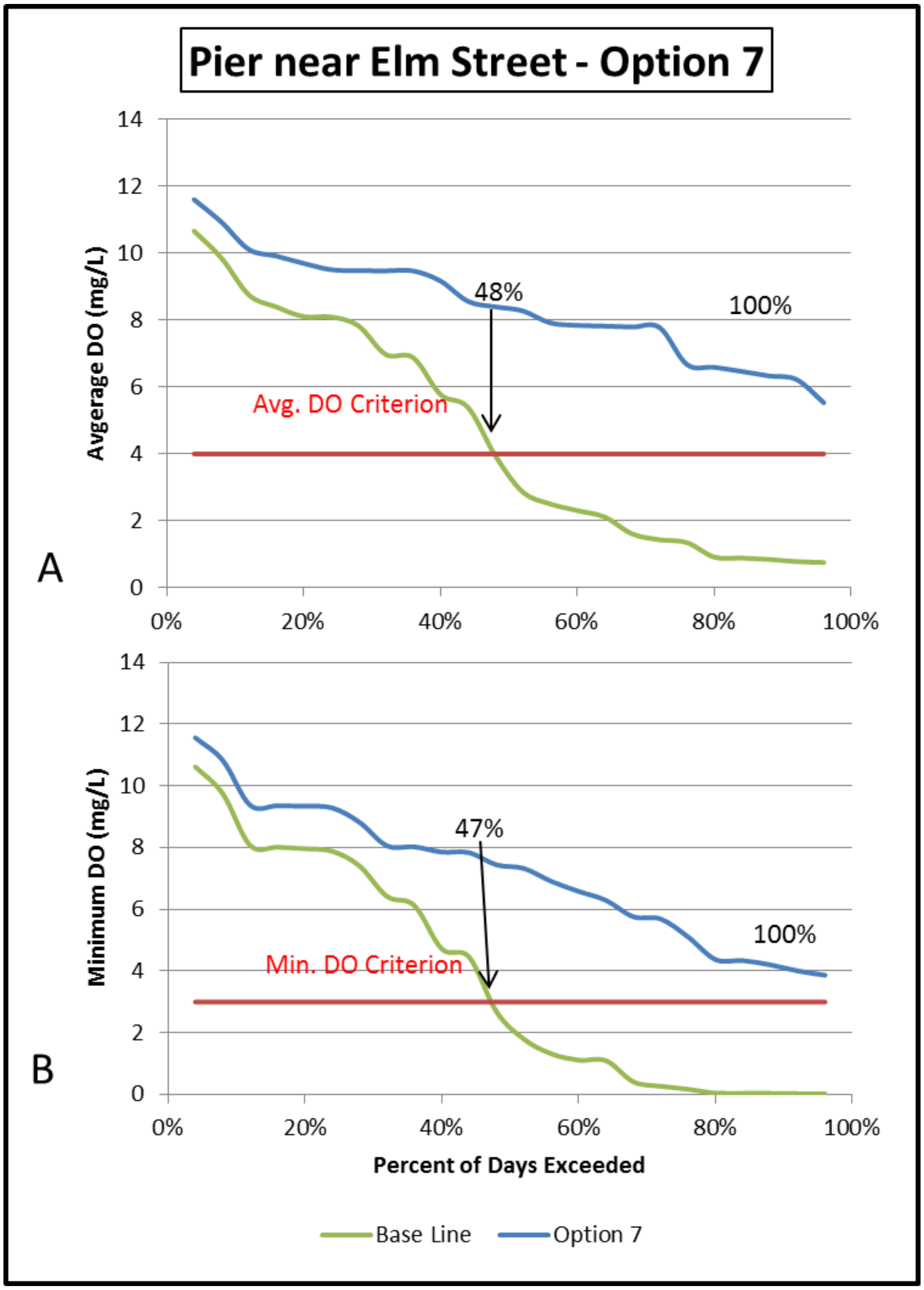


Figure 32 **Dissolved oxygen duration curves of minimum concentrations within Urban Brady Creek for baseline condition and Management Option 7 (monthly scenarios for 2005 & 2006)**

7.5.2 Summary of Management Options

A combination of urban stormwater BMPs coupled with seasonal (April – October) pumping of the City of Brady WWTF effluent to the top of Urban Brady Creek will achieve significant improvement in DO concentrations and may be able to achieve the desired water quality improvement. Table 7 below summarizes the results of the QUAL2K management measures evaluation. Management option 7 is the one option modeled that indicates the potential attainment of minimum DO standards 100% of the time.

Table 7 Summary of 24-hr minimum DO exceedance graphs for baseline and management option conditions considering the percent time the absolute minimum DO criterion is obtained at FM 1776

Option	Brief Description	Elm St. Pier % time 24-hr min. DO ≥ 3.0 mg/L	Elm St. Pier % time 24-hr avg. DO ≥ 4.0 mg/L	Urban Brady % time 24-hr min. DO ≥ 3.0 mg/L	Urban Brady % time 24-hr avg. DO ≥ 4.0 mg/Lr
None	Existing baseline conditions	47	48	47	48
1	25% reduction in SOD	53	54	53	53
2	50% reduction in SOD	73	77	70	75
3	Pump effluent above “eastside” pool	64	68	47	45
4	50% reduction in SOD & pump effluent above “eastside” pool	100	100	94	89
5	Pump effluent to “eastside” pool with diffuser	69	75	62	54
6	25% reduction in SOD & pump effluent to “eastside” pool with diffuser	76	100	75	72
7	50% reduction in SOD & pump effluent to “eastside” pool with diffuser	100	100	100	100

8.0 SWMM MODEL APPLICATION (BRADY CREEK URBAN STORMWATER)

8.1 MEASURED DATA FOR SWMM CALIBRATION

The monitoring aspects of the project were conducted by the City of Brady and the Upper Colorado River Authority. Three urban stormwater stations (i.e., 20067, 20811, and 20812) shown in Figure 33 were selected to monitor urban stormwater. The sites were monitored for quantity, i.e. 15-minute water level data recorded during storm events and sampled for water quality (UCRA, 2010a). Storm samples were analyzed for total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrite + nitrate nitrogen (NO_2+NO_3-N), and five-day biochemical oxygen demand (BOD). For use in the SWMM modeling, TKN and NO_2+NO_3-N concentrations were added to give total nitrogen (TN).

Due to persistent drought conditions and the resulting sparsity of storm events during the time frame stipulated for sampling, a total of only five storm events were monitored. Consequently, it was impossible to accomplish the sampling plan and the model verification process requirements delineated in the *Brady Creek Watershed Protection Plan QAPP* and the *Modeling Efforts for the Brady Creek Watershed Protection Plan QAPP*. Only, two storm events, one on September 13, 2012 and the other on September 27, 2012, were measured at stations 20067 and 20811, and one storm event on September 27, 2012 was measured at station 20812.

A description of each stormwater station and a map, Figure 33, of their locations follow:

- Station 20067: Brady Creek south bank stormwater inlet 405 meters upstream of US 190 bridge,
- Station 20811: Stormwater drainage ditch to Brady Creek near FM 2309, and
- Station 20812: Stormwater drainage ditch on Old Brady Road near US 71/US 87 intersection

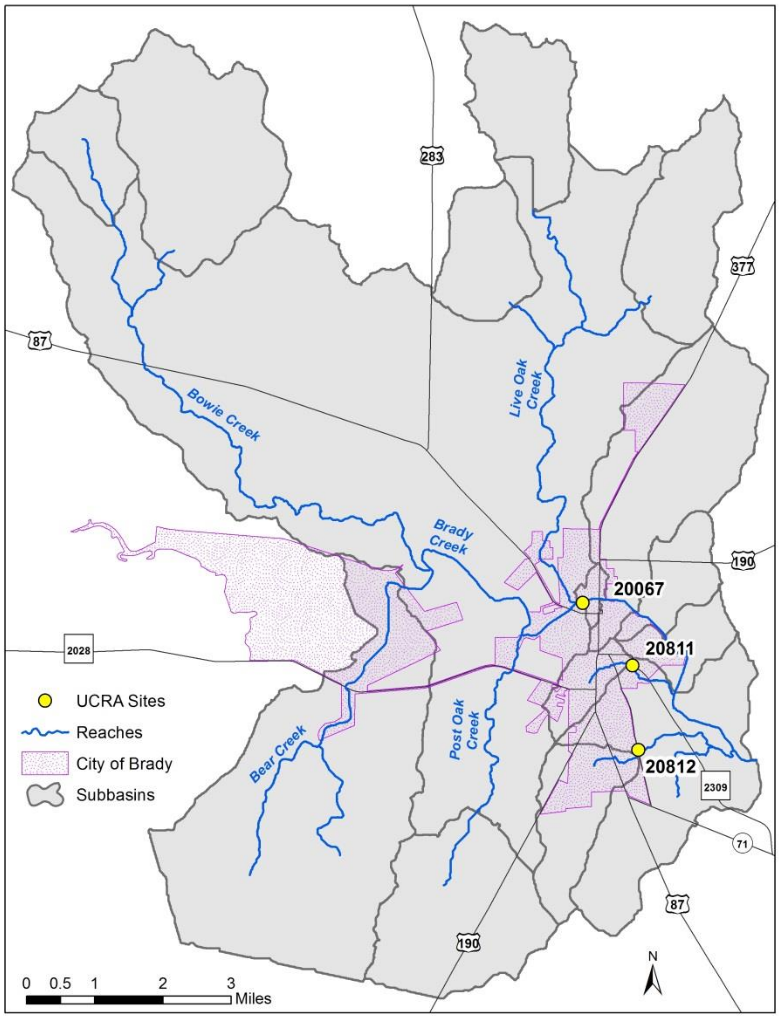


Figure 33 Map of City of Brady showing three stormwater monitoring stations

The drought conditions and limited storm events cannot be altered, but the results were that too few events were captured to allow SWMM to be calibrated and validated (combined, the verification process) as was planned in the project modeling QAPP (UCRA and TIAER, 2012). Storm event data limitations constrained the model verification process to only the calibration step. The two monitored storm events for stations 20067 and 20811 were used for calibration. As required in the project modeling QAPP, ISCO model 3230 automatic samplers were used to collect samples and measure flow from these events. Rainfall amounts were obtained from USGS streamflow station 08145000 (Brady Creek at Brady).The single event for station 20812 was excluded from calibration, because this location had only one event and UCRA staff indicated that a relatively large pond or stock tank of unknown dimensions acted to detain an unknown amount of the stormwater upstream of the station. The storm event data at two monitoring sites are summarized in Table 8. To provide additional context, the total 24-hour rainfall for these two events were compared to daily rainfall data at the City of Brady (NCDC, 2011a) for the 10-year period of 2000 through 2009, which is the period used in the SWMM BMP modeling applications discussed later in this chapter. Single day rainfall events exceeding 3 inches in 24 hours occurred only 4 times out of 740 rainfall events of 0.01 inches or more during this 10-year period. The larger of the two events had a measured rainfall of 3.36 inches, indicating it was an uncommonly large event. In contrast, for this 10-year period there were 294 single day rainfall events exceeding the 0.24 inches of the small event, and this event was close in rainfall amount to the median rainfall of 0.16 inches.

Table 8 Water quantity and quality measured at stormwater monitoring sites 20067 and 20811.

Storm Event	Water Quantity and Quality Parameters	Catchment for Station 20067	Catchment for Station 20811
09/13/2012	Precipitation (inch)	0.24	0.24
	Storm Volume (ac-ft)	0.066	0.363
	Peak Flow (cfs)	0.4	1.1
	TSS (mg/L)	63	582
	TP (mg/L)	0.223	0.699
	TN (mg/L)	1.687	3.93
	BOD (mg/L)	7.2	8.7
09/27/2012	Precipitation (inch)	3.36	3.36
	Storm Volume (ac-ft)	7.04	14.85
	Peak Flow (cfs)	30	75
	TSS (mg/L)	778	1860
	TP (mg/L)	3.76	0.3
	TN (mg/L)	18.167	2.161
	BOD (mg/L)	45.7	39.9

8.2 SWMM MODEL CALIBRATION

As previously mentioned, the model verification process outlined in the modeling QAPP (UCRA and TIAER, 2012) had to be altered with only two storm events for each of the two catchments, the SWMM model could only be calibrated, and even the calibration was limited. The two storm events for stations 20067 and 20811 varied in the amount of rainfall by a factor of 14 and the peak runoff and total storm volumes by about 2 orders of magnitude.

Further, regarding the water quality routines within SWMM, the option defining event mean concentrations (EMCs) as input data was used because there were inadequate data to develop the model to reliably predict runoff water quality. Under the EMC option, the user specifies as input the concentration of each desired water quality constituent that SWMM will predict. With the EMC option there is no need to calibrate the water quality portion of the model, since the input EMCs will be very close to what SWMM predicts in its output as the storm event EMC. Therefore, SWMM calibration was only performed for the hydrologic portion of the model.

For the application of SWMM, the drainage area of each station was defined as a catchment, which is the smallest areal unit used in the model, and separate SWMM models were created for each catchment. The land uses of the two catchments are provided in Table 9. The impervious area for each catchment was estimated based on SWMM manual (Rossman, 2009) guidance on impervious covers associated with different land uses. These impervious area estimates were then used to define two sub-catchments within each catchment, one that represented the fraction of the area that was impervious cover and the other the fraction that was pervious cover. The precipitation data used for SWMM model input was obtained from precipitation data recorded on corresponding stormwater monitoring event dates at USGS streamflow station 08145000 (Brady Creek at Brady). Table 10 provides the values for the other input parameters used in the SWMM hydrology calibration. These input values were determined through adjustments made during model calibration and the physical characteristics and prevalent soils of each catchment.

Table 9 Land use for two catchments used in SWMM calibration process

Land Use	Catchment for station 20067	Catchment for station 20811
Residential	88.00	393.40
Commercial and Services	17.00	45.20
Cropland and pasture	-	9.91
Rangeland	-	60.02
Transitional areas	-	53.36
Total Area	105.00	561.89

(Source UCRA (2010).

Table 10 SWMM calibration input parameters

SWMM Parameters	Catchment for Station 20067	Catchment for Station 20811
Width of overland Flow Length (ft)	9,148	48,952
Slope (%)	0.5	0.5
Percent of Impervious Area (%)	38.9	27.8
Manning N for Impervious area	0.011	0.1
Manning N for pervious area	0.05	0.24
Depth of Depression storage on impervious area (in)	0.12	0.17
Depth of Depression storage on pervious area (in)	0.22	0.22
Percent of Impervious Area with no depression area (%)	5	5
Subarea routing	Pervious	Pervious
Percent of runoff routed between subareas	50	45
Infiltration: suction head (inch)	8.27	7.81

Infiltration: conductivity (in/hr)	0.28	0.3
Infiltration: Initial Deficit	0.31	0.291

The SWMM hydrologic calibration results comparing measured and predicted storm event peak flow and total volume are provided in Table 11. The hydrologic calibration proved to be a challenge. No unique set of reasonable input parameters could be determined that resulted in an acceptably accurate simulation of both storm events at the two stations. Based on previous experience of the modelers, it is not uncommon for difficulties to arise in determining a unique set of model input parameters that allow adequate simulation over a full range from very small to large storm events. Therefore, it is considered likely that the very large differences in the size of the two storm events monitored, as mentioned above, was the cause of the challenges faced in the calibration process.

Table 11 SWMM model hydrologic calibration results

Stations Storm Events		20067 9/13/2012	20067 9/27/2012	20081 9/13/2012	20081 9/27/2012
Peak flow (cfs)	Measured	0.40	31	1.10	73
	Simulated	0.41	117	1.09	313
Total volume (ac-ft)	Measured	0.05	13	0.23	37
	Simulated	0.08	12	0.40	41

Based on typical historic storm intensity and duration in the Brady area, it is more likely that future conditions will see a higher frequency of smaller storm volume events, similar to and somewhat larger in size than the September 13th event, and a lower frequency of larger storm volume events comparable to the September 27th event. Moreover, it is more likely that the smaller events are more detrimental to water quality in Urban Brady Creek than are the larger events. Smaller events essentially dump their loads into the creek and the lack of flushing flows concentrates and deposits pollutants, whereas larger events produce enough flow to dilute pollutants and pass them through the system. Because of these two probabilities, it was decided during the calibration process to put more weight on reasonable predictions of the peak flow for the small, September 13th event. The simulated peak flow for the large September 27th event was over predicted by a factor of 4 at both stations. Graphical comparison of calibration results are provided for Station 20067 and 20081 in Figure 34 for the September 13, 2012 event and in Figure 35 for the September 27, 2012 event.

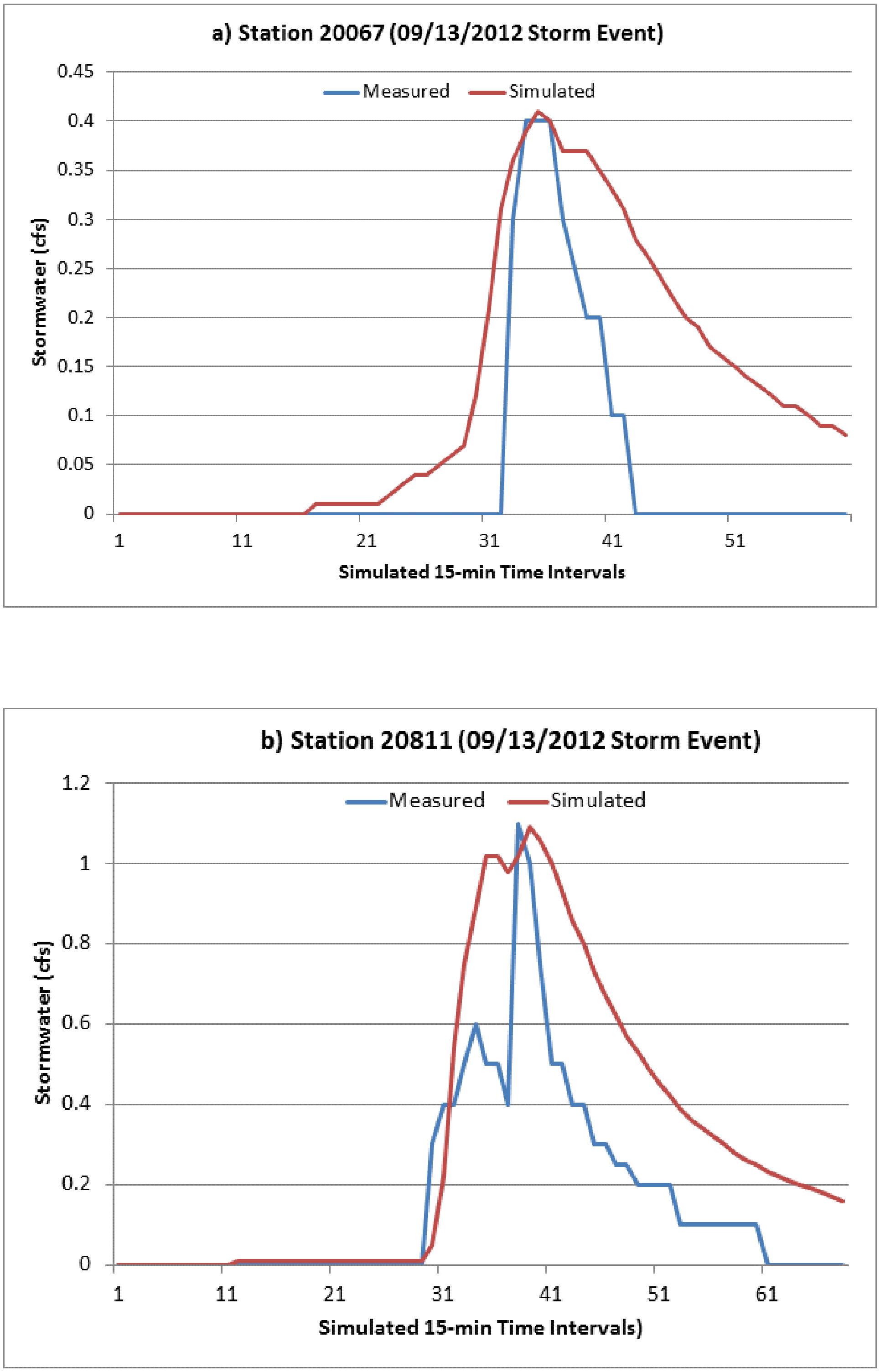
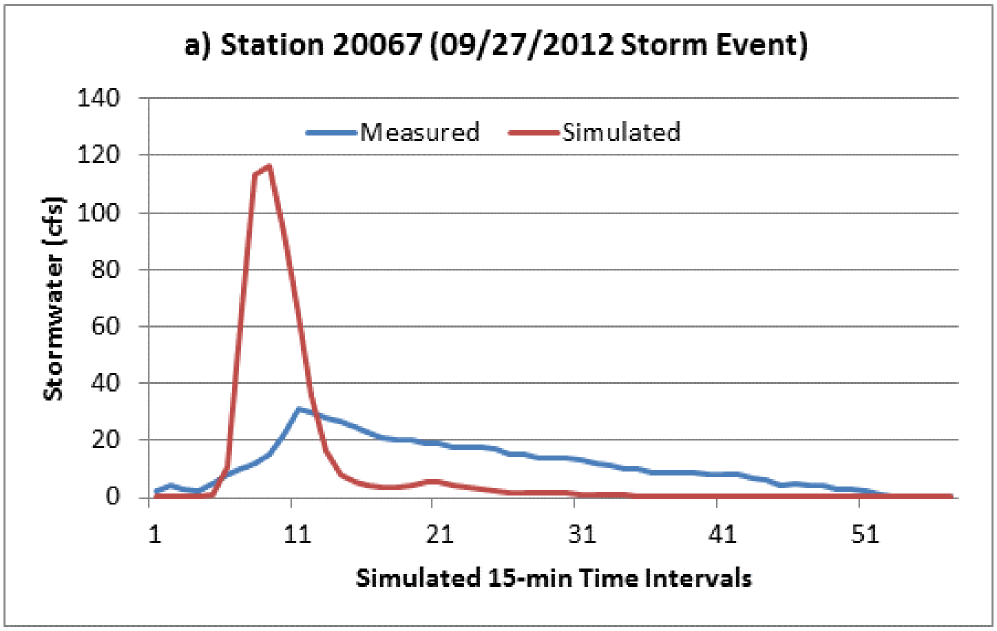


Figure 34 **Measured and simulated results for the September 13, 2012 storm event; a) Station 20067 and b) Station 20811**



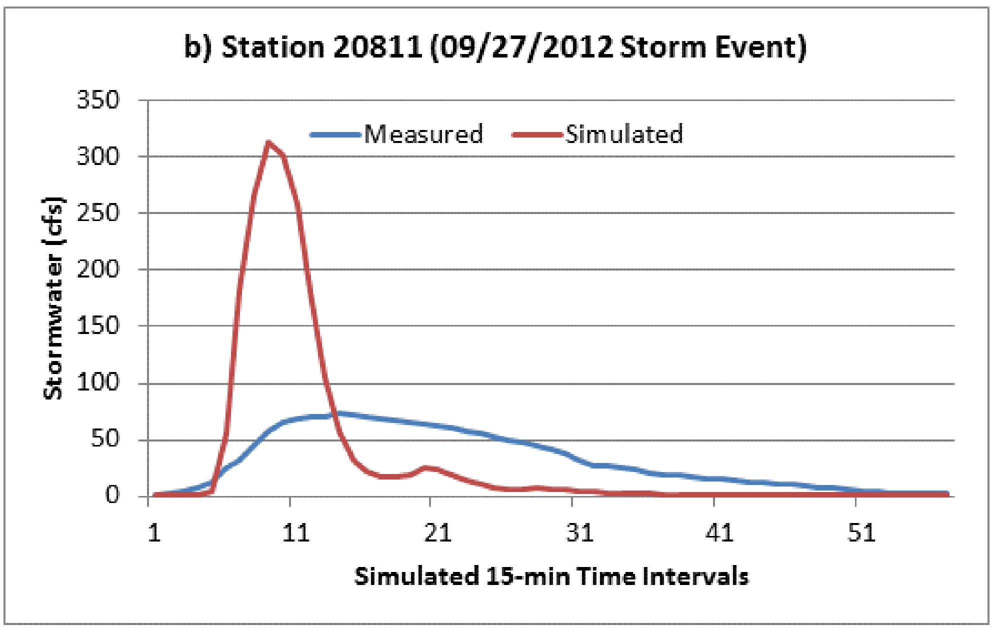


Figure 35 **Measured and simulated results of the September 27, 2012 storm event; a) Station 20067 and b) Station 20811**

The goals stated in the modeling QAPP for acceptable calibration are provided below:

- Stormwater volume for individual events will be calibrated so that predicted values agree with measured values within 40 percent.
- Peak stormwater flow for individual events will be calibrated so that predicted values agree with measured values within 30 percent.

The stormwater volume goal was obtained for the large September 27th event at both stations and for peak flows during the small September 13th events at both stations. The peak flow goal was not realized for the large September 27th event by a wide margin. By a smaller margin of unacceptability, the stormwater volume acceptance goal was not realized for the small September 13th event where simulated total volumes were 60% and 74% higher than measured total volume at Stations 20067 and 20081, respectively.

While this calibration exercise was less than optimal, the resulting SWMM models of the catchments of stations 20067 and 20081 were considered as sufficiently reliable for use in estimating existing loadings and reductions in loadings of urban stormwater pollution to Urban Brady Creek. As stated earlier the availability of only two of measured stormwater events for model calibration and absence of any events for validation, portends model results from the application of the SWMM model with a high potential of uncertainty. The over-prediction of peak runoff for the larger of the two events portends over-design of the stormwater BMPs evaluated in Section 9 herein. Because efficiency of the BMPs considered has an inverse relationship to flow, an over-estimation of peak flow for large rainfall events means that the model will under-predict removal efficiencies of the BMPs for these same large events.

A sensitivity analysis was not performed on the SWMM input parameters, though the model is quite sensitive to most of the parameters listed in Table 10. Because of the lack of data for robust calibration of SWMM, the expectations are that uncertainty could be high in the results obtained from model application.

9.0 SWMM MODEL APPLICATION (TO REDUCE URBAN LOADINGS)

Considerations for Evaluation of Urban Stormwater Management

The application of SWMM to the urban areas of the City of Brady consisted of developing a baseline pollutant loading estimate based on individual SWMM models of multiple subbasins and estimates of pollutant load reductions from stormwater management. The pollutants considered in the application were BOD, TSS, TN and TP. The same urban subbasins used in previous evaluations of urban pollutant loading from the City of Brady (UCRA 2010b and UCRA 2004) were used in this modeling exercise (Figure 36).

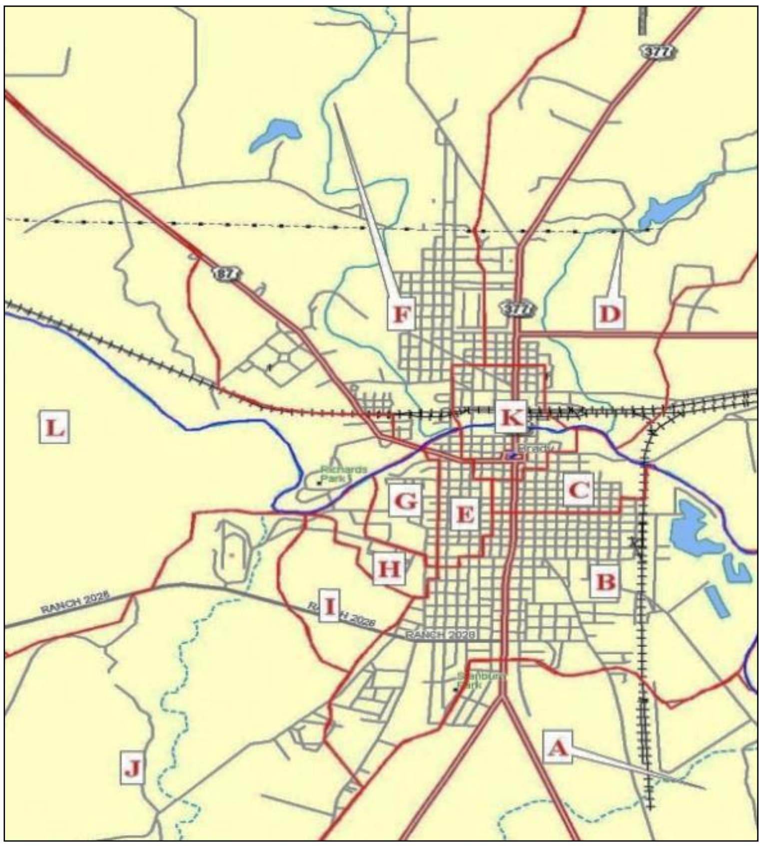


Figure 36 Subbasins of City of Brady

By using the EMC feature in SWMM, model water quality operation did not rely on pollutant build-up and washoff factors that typically require extensive data for meaningful development. Further, as will be subsequently discussed, by using historical stormwater data for the City of Brady to define the EMCs for BOD, TSS, TN, and TP, the reliability of predicted baseline (or existing) pollutant loadings was anticipated to be increased as compared to using other means within SWMM that require substantial amounts of data.

As presented in Section 7.5 herein, reductions in SOD and sediment nutrient fluxes associated with stormwater loadings were part of the system of control measures required to improve the depressed DO in Urban Brady Creek. The SOD and nutrient fluxes from the sediments result from the settling of particulates to the streambed, particularly in pooled areas. These settleable particulates have two major sources: storm events and baseflow conditions. As described in the QUAL2K modeling effort, the model uses a submodel containing a sediment diagensis formulation to determine the SOD and nutrient fluxes under baseflow conditions from the settling of suspended algae and detrital materials included in the simulation. The user, however, must prescribe SOD and nutrient fluxes that are residuals from storm events as input. These storm-related SOD and nutrient fluxes were estimated through the calibration and validation processes for QUAL2K, and it was these user prescribed, stormwater related values that were considered to be reduced through urban stormwater management.

Based on onsite observations of subbasin outlets to Urban Brady Creek, any urban management measure considered for the City of Brady within the immediate drainage area of Urban Brady Creek was required to have a small footprint because of the absence of sufficient open space to allow traditional wet or dry ponds. Based on experience with urban stormwater management with the City of San Angelo, UCRA recommended consideration of hydrodynamic vortex separators, specifically the Aqua-Swirl® Hydrodynamic Separator by AquaShield. Aqua Swirl® comes in several diameters sizes ranging from as small as 2-foot diameter to as large as 12-foot diameter in order to accommodate different design flows. A schematic of the Aqua Swirl® design is provided in Figure 37.

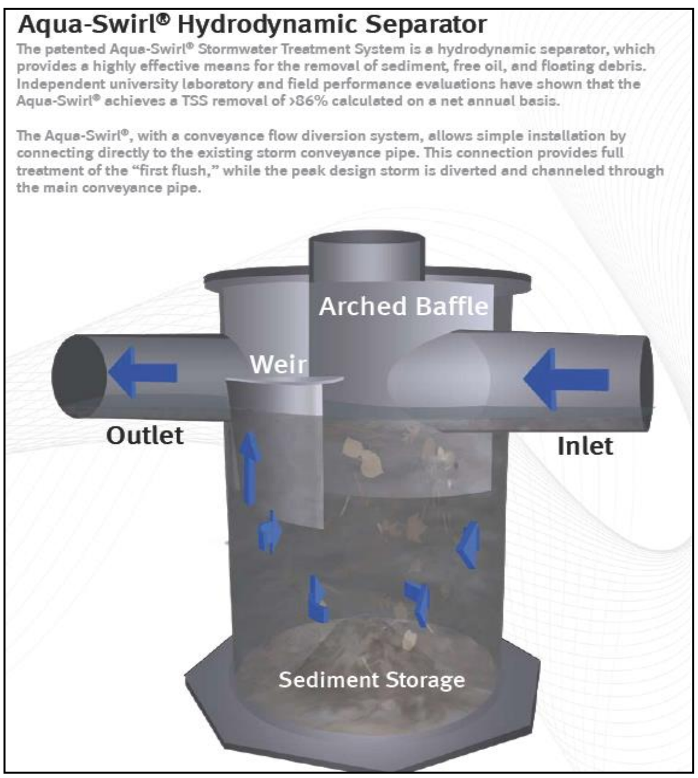


Figure 37 Schematic of Aqua-Swirl (The mention and use of Aqua-Swirls® by AquaShield in this WPP is not an endorsement of this equipment.)

The number and size of vortex separators to be installed in each subbasin are discussed in Section 9.5 herein. The vortex separators will be installed at the outfall to Brady Creek of each subbasin.

The following 4 paragraphs describing the description and operation of the Aqui-Swirl® hydrodynamic separators is from the AquiShield Inc. website (reference here).

The Aqua-Swirl® is designed to provide a high level of water quality treatment through the use of a single swirl chamber. Operation begins when stormwater enters the Aqua-Swirl™ by means of its tangential inlet pipe thereby inducing a circular (swirl or vortex) flow pattern. The swirl chamber represents the effective treatment area of the device where both the capture and retention of sediment, debris and free floating oil occur. A combination of gravitational and hydrodynamic drag forces results in solids dropping out of the flow. Particles settle and migrate to the center of the swirl chamber floor where velocities are the lowest. The captured (settled) particles are retained in a cone shaped sediment pile at the base of the swirl chamber. The treated flow exits the swirl chamber behind an arched inner baffle that is positioned opposite the influent pipe and in front of the effluent pipe.

The top of the baffle is sealed across the treatment channel to eliminate floatable pollutants from escaping the swirl chamber. A vent pipe is extended up the riser to expose the backside of the baffle to atmospheric conditions, thus preventing a siphon from forming at the bottom of the baffle. Water is retained within the swirl chamber between storm events to a level equal to the invert elevations of both the influent and effluent pipes.

An offline Aqua-Swirl® configuration uses a separate diversion structure, or weir device located upstream of the unit. The diversion structure is designed to direct only the designed water quality treatment flow through the swirl chamber. Twin or multiple Aqua-Swirl™ system configurations can be implemented to allow for higher treatment flow capabilities beyond that of a single unit.
An inline (online) configuration uses an internal conveyance flow diversion (CFD) design to provide full treatment for the most contaminated first flush, while the cleaner peak storm flow is diverted and channeled through the main conveyance pipe.

The 10-year period of January 1, 2000 through December 31, 2009 was selected for simulation for each urbanized area based on the need to include a sufficiently long period to include wet, dry, and normal precipitation periods, but to be short enough to be manageable in the operation of SWMM. The 15-minutes rainfall data for the 10-year period was obtained from the National Oceanic and Atmospheric Administration National Climatic Data Center (NCDC) website (NCDC, 2011a) for City of Brady.

9.1 DEVELOPMENT OF SWMM CATCHMENT MODELS

The approach to evaluate urban stormwater runoff involved development of a SWMM model for each of the urban areas previously considered in the City of Brady watershed characterization (UCRA, 2010b). The various subbasins considered in the previous characterization are shown in Figure 36 and the urban land use characteristics are provided in Table 12. The basic input parameters for the urban area of each subbasin were based on the values developed in the calibration of SWMM (Table 10). Each subbasin was represented as a single catchment in the SWMM model development. Subbasin K was separated into North and South subbasins, because Brady Creek bisects its drainage area in roughly an east-west direction. Since Subbasins J and L on the western portion of the City of Brady do not include consequential amounts of urban land use, SWMM models were not developed and applied for these two subbasins.

Table 12 Urban land-use characteristics of City of Brady catchments

Urban Subbasin	Residential (ac.)	Commercial (ac.)	Industrial (ac.)
A	100	400	100
B	740	200	200
C	90	45	15
D	116	83	133
E	88	17	0
F	210	140	0
G	112	0	0
H	100	0	0
I	220	0	0
J	0	0	0
K	24	192	24
L	0	0	0
Total	960	497	172

Source: UCRA (2010b)

9.2 DEVELOPMENT OF EMCS FOR SWMM INPUT

As stated previously, insufficient water quality data existed to allow the SWMM calibration process to use the build-up and washoff features of the model to make predictions of the quality of stormwater. Instead, a feature of SWMM was used whereby the user specifies the EMC concentration of each desired pollutant as input, and that concentration becomes the concentration predicted by the model. Under certain situations there may be some slight departures of the model predicted concentrations from the user input EMC, but these are minor deviations. Also, the measured data limitations did not allow spatial specificity in defining EMCs, resulting in the same EMCs being used for all the subbasins. For this study the pollutants of concern were TSS, BOD, TN, and TP.

The EMCs for TSS, BOD, TN, and TP were set equivalent to the median concentration of the historical stormwater data collected in the urban subbasins of the City of Brady. These data were available from stormwater data collected during the present study and the Brady Creek watershed characterization study (UCRA, 2010b). The EMCs derived from these sources and used in the SWMM models of the City of Brady subbasins are provided in Table 13.

Table 13 EMCs used in baseline and BMP SWMM simulations

Water Quality Parameter	EMC (mg/L)

TSS	118
BOD	9
TP	0.7
TN	3.9

9.3 BASELINE POLLUTANT LOADING PREDICTIONS

Each SWMM model of the urban subbasins within the City of Brady was operated for the 10-year period of January 1, 2000 through December 31, 2009. The water quality results for baseline conditions without any BMPs area provided in Table 14 as annual average loadings for the 10-year simulation period. The entire urban area of the City of Brady includes several areas that drain into Brady Creek downstream of the area where depressed DO has occurred, i.e., are located downstream of the Urban Brady Creek reach. These downstream subbasins are designated as A and B on Figure 36. Also, Subbasins J and L drain into Brady Creek upstream of Urban Brady Creek, but contain inconsequential amounts of urban area, and therefore estimations of urban pollutant loadings were not made for these two subbasins. In Table 14 a subtotal of the annual average pollutant loadings are provided for those subbasins draining directly into Urban Brady Creek (Subbasins C, D, E, F, G, H, I, K North, and K South). This subtotal from subbasins directly discharging into Urban Brady Creek provided an estimate of annual average stormwater loadings of TSS, BOD, TN, and TP possibly affecting DO in the creek. It should be recognized that an undetermined portion of these stormwater loadings will not end up entirely in Urban Brady Creek, but will be transported further downstream. Especially during the larger storm events, the portion of the pollutant loadings transported downstream would be expected to be substantial, and a higher portion would be expected to be retained in Urban Brady Creek for smaller events. The total pollutant loadings for the entirety of the urban area of the City of Brady are provided in the last row of Table 14.

Table 14 SWMM predicted baseline-condition annual average hydrologic and pollutant loading results by urban area subbasin for January 1, 2000 to December 31, 2009

Urban Subbasin	Storm Volume (million gallons)	TSS (lbs)	TP (lbs)	TN (lbs)	BOD (lbs)
A	6.67	6,217	37	207	474
B	84.92	79,056	469	2,633	5,933
C[a]	9.64	8,905	53	297	679
D[a]	29.24	27,771	165	925	2,118
E[a]	9.64	9,088	54	303	670
F[a]	66.52	62,838	373	2,093	4,793
G[a]	7.20	6,629	39	221	506
H[a]	7.20	6,613	39	220	504
I[a]	17.99	16,600	98	553	1,266
J[b]	-	-	-	-	-
K (North) [a]	6.00	5,524	33	184	421
K (South) [a]	6.68	6,147	36	205	469

L[b]	-	-	-	-	-
Total Urban Brady Creek		150,115	891	5,000	11,426
Total Entire Urban Area		235,387	1,396	7,840	17,833

[a] These subbasins comprise the urban areas draining into Urban Brady Creek as defined in the DO model.
[b] Subbasins J and L contain inconsequential amounts of urban land use and were not modeled with SWMM.

9.4 DEFINING REMOVAL EFFICIENCIES OF STORMWATER MANAGEMENT OPTIONS

To evaluate the pollutant removal from an urban control practice, SWMM requires as input an equation defining the efficiency of a BMP in removing pollutants. For this application published removal efficiency information for Aqua-Swirls® and the experience of UCRA with urban BMPs in nearby San Angelo, TX were combined to develop these equations. Both TSS and BOD were given the same removal equation and TP and TN were characterized with a different equation. The removal efficiencies of TP/TN were assigned lower values than TSS/BOD because of an assumed higher dissolved fraction comprising these parameters as compared to BOD and TSS. The pollutant removal equation within SWMM was defined in the model input as the fractional amount of pollutant remaining (i.e., 1 – fraction removed). Separate pollutant removal equations were developed for each diameter size of the Aqua-Swirl® units evaluated. The 9-foot diameter unit is provided as a typical result in Figure 38.

The two curves on Figure 38 were based on fitting a fourth-order polynomial through points calculated to reflect changes in pollutant removal as a function of flow and expressed as fraction of pollutant remaining. Defining the removal as fraction of pollutant remaining, as opposed to fraction removed, provided more ready use as SWMM input. The basis of the curves was a technical report on pollutant removal efficiency of Aqua-Swirls® based on surface loading rate (gallons per minute per square foot) found in Tennessee Tech University (No Date). The black line depicts the performance for TSS and BOD removal expressed as fraction remaining. The line reflects the decreasing removal efficiency of the unit as flow increases until a flow greater than 12 to 14 cfs, when the 9-foot diameter unit provides only nominal removal. The red line on Figure 38 provides an estimate of the performance for TN/TP removal, reflecting UCRA's experience with BMPs in the City of San Angelo which indicated that removal for nutrients is about ½ that for BOD and TSS (Teagarden, 2011).

By providing the fourth-order polynomial equation as input into SWMM, the model was able to dynamically vary pollutant removal as a function of flow within each simulated stormwater event over the 10-year period of January 1, 2000 through December 31, 2009.

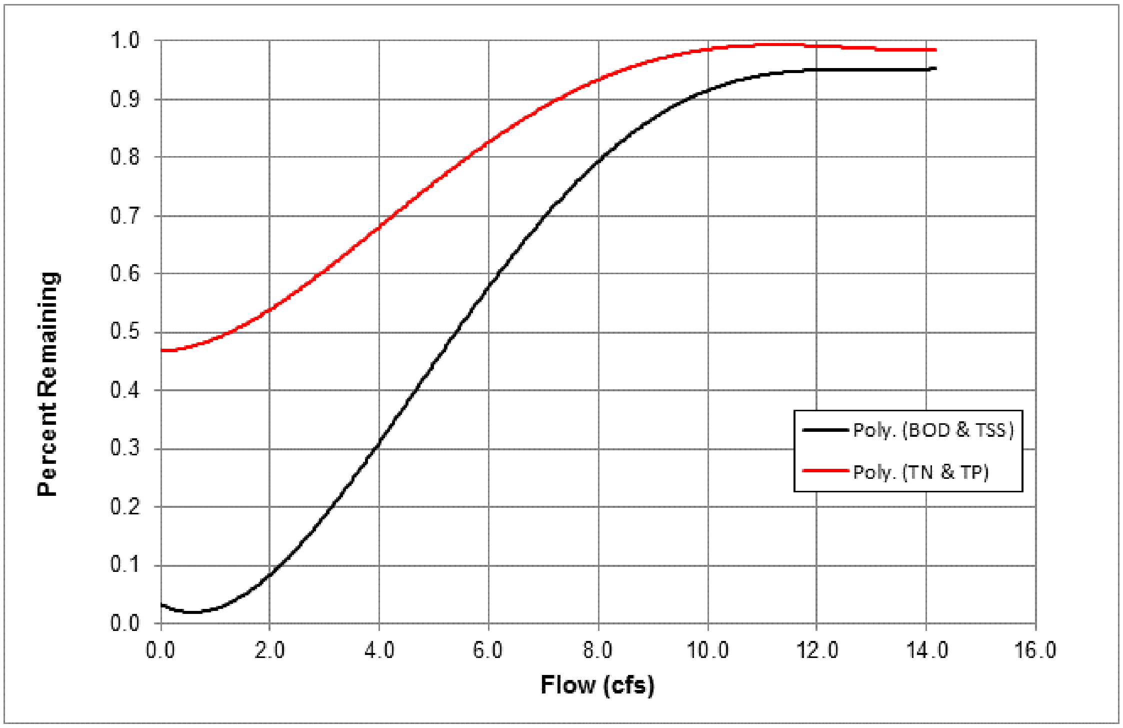


Figure 38 Fraction remaining of stormwater pollutant for 9-foot diameter unit

9.5 EVALUATING STORMWATER MANAGEMENT PRACTICES

As discussed above, the small footprint area available for urban BMPs precluded consideration of such traditional control measures as wet ponds and dry ponds in the areas adjacent to Urban Brady Creek. The areal constraints dictated consideration of vortex separators such as the Aqua-Swirl® units used for this evaluation. Space is available within Subbasins A and B for wet ponds and dry ponds, but because these areas enter Brady Creek downstream of Urban Brady Creek, it is unlikely that BMPs would be considered in these areas for this project. However, for consistency of analysis, Subbasins A and B were also evaluated considering Aqua Swirls®. These units are typically sized based on some design storm characterized by an associated peak flow. As shown in Figure 38 the percent of pollutant remaining increases as the flow through the unit increases. Since the flow is dynamic over a stormwater event, the removal efficiency changes with time and flow during the event.

Determining the sizing and number of units for each subbasin was considered more art than science, given the complications of estimating how much of stormwater reduction would actually be realized in reductions of SOD and nutrient release rates in the pools of Urban Brady Creek. Assumptions (including supporting references) regarding the relationship of stormwater reduction to reduction in SOD and nutrient releases are discussed on pages 33, 34 and 67 of the modeling study (Appendix B). The following relevant observations provide insight into the level of complexity of this relationship. First, it is likely cost prohibitive to size the units to treat the peak flows of large, infrequent return interval events. Second, these infrequent large events, however, would carry a disproportionate amount of the pollutant loadings within a year. Third, these large events could, however, produce high enough flows and associated velocities in Urban Brady Creek that much of the pollutant loadings would remain in suspension and would not be deposited in the areas of depressed DO, but rather, would be carried further downstream. Fourth, small events would occur much more frequently than the large events and a higher percentage of the untreated pollutant loadings from these small events was considered likely to be deposited in Urban Brady Creek, possibly adding disproportionately to SOD and nutrient flux release potential in the pools indicated by the QUAL2K model to have the lowest DO.

The approach taken in this study was to determine the sizing and number of units based on a goal of removing on average about 50 percent of the TSS and BOD loadings over the 10-year simulation period. Suitable sites are available at or very near the outfall to Brady Creek of each subbasin, which will allow for installation of the number of hydrodynamic vortex separators required to achieve the needed reductions in TSS, TN, TP and BOD as predicted by the model. In Table 15, the results for the 10-year simulation period are summarized as percent reductions for stormwater volume, TSS, TP, TN, and BOD. As expected, Aqua Swirl® units do not alter stormwater volume, and based on the fraction of pollutant remaining relationships input to SWMM, the percent removals are identical for TSS and BOD and for TP and TN.

Table 15 SWMM predicted annual average percent removal of stormwater volume, TSS, TP, TN, and BOD by urban area subbasin for January 1, 2000 to December 31, 2009.

Urban Subbasin	Stormwater Volume (%)	TSS (%)	TP (%)	TN (%)	BOD (%)	Aqua-Swirl® Size (# of units)[a]
A	0	49	24	24	49	9(1)
B	0	49	25	25	49	12 (12)
C[b]	0	53	27	27	53	9(1)
D[b]	0	44	21	21	44	12 (6)
E[b]	0	56	28	28	56	10(1)
F[b]	0	40	20	20	40	12 (6)
G[b]	0	50	25	25	50	9(1)
H[b]	0	45	22	22	45	9(1)
I[b]	0	44	22	22	44	12(1)
J[c]	-	-	-	-	-	-
K (North) [b]	0	52	26	26	52	9(1)
K (South) [b]	0	50	25	25	50	9(1)
L[c]	-	-	-	-	-	-
Total Urban Brady Creek[d]	0%	48%	24%	24%	48%	-
Total Entire Urban Area[d]	0%	48%	24%	24%	48%	-

[a] The diameter of the unit and the number of units must be considered approximate given the high uncertainty in SWMM predictions of peak flows.
[b] These subbasins comprise the urban areas draining into Urban Brady Creek as defined in the DO model.
[c] Subbasins J and L contain inconsequential amounts of urban land use and were not modeled with SWMM.
[d] Percent removals computed as a simple average of the subbasins comprising this category.

Additional insights can be gleaned into annual variability of removal efficiencies by considering Subbasin E, which is the same subbasin as stormwater Station 20067. The baseline characteristics of peak flow, stormwater volume, and pollutant loadings for Subbasin E are provided in Table 16. The main point from the data in this table is the inter-annual variations in the stormwater conditions predicted by SWMM for Subbasin E. The most stormwater runoff was predicted for the year 2000, and loadings were about two or three times greater that year than for the 10-year average. The year with the least stormwater runoff was 2008, and loadings were about a factor of 10 less that year than the average. These inter-annual variations in stormwater quantity and quality manifest themselves in yearly variations in the percent removal of the pollutants (Table 17). In the dry years of 2002 and 2008, predicted removal efficiencies for TSS and BOD where over 80 percent. In the wet year of 2000, the removal efficiencies for TSS and BOD dropped to just over 30 percent. This same year-to-year variability would be reflected in variability of removal efficiencies for storm events as a function of peak flows and storm hydrograph shape.

Table 16 SWMM predicted baseline-condition annual average hydrologic and pollutant loading results for Subbasin E (January 1, 2000 to December 31, 2009)

Year	Peak Flow (cfs)	Total Volume (million gal)	TSS (lbs)	TP (lbs)	TN (lbs)	BOD (lbs)
2000	139.71	22.68	21,866	130	728	1,612
2001	47.45	11.81	11,125	66	371	820
2002	15.78	2.98	2,714	16	90	200
2003	45.92	8.60	8,088	48	269	596
2004	49.55	11.93	11,007	65	367	812
2005	62.09	9.38	8,757	52	292	646
2006	95.67	11.74	10,986	65	366	810
2007	46.21	12.34	11,686	69	389	862
2008	16.40	0.95	830	5	28	61
2009	63.10	4.00	3,817	23	127	281
Average	58.19	9.64	9,088	54	303	670

Table 17 SWMM predicted annual percent reductions of peak flow, stormwater volume, TSS, TP, TN, and BOD for Subbasin E (January 1, 2000 to December 31, 2009)

Year	Peak Flow (cfs)	Total Volume (million gal)	TSS (lbs)	TP (lbs)	TN (lbs)	BOD (lbs)
2000	3%	0%	31%	15%	15%	31%
2001	11%	0%	67%	34%	34%	67%
2002	29%	0%	85%	45%	45%	85%
2003	15%	0%	68%	35%	35%	68%
2004	32%	0%	78%	39%	39%	78%
2005	13%	0%	63%	32%	32%	63%
2006	7%	0%	45%	22%	22%	45%
2007	4%	0%	61%	30%	30%	61%
2008	44%	0%	84%	42%	42%	84%
2009	14%	0%	54%	27%	27%	54%
Average	12%	0%	56%	28%	28%	56%

Inferred from these observations is that the larger stormwater events overwhelm the BMPs, but the associated larger flows to Urban Brady Creek flush the system to some degree, and much of the large event loadings will not only pass through the BMPs, but also pass through Urban Brady Creek. It is the small events that dump first-flush loads into Urban Brady Creek without enough flow volume to pass the pollutants through the system that are more detrimental to DO. The proposed BMPs will function best at removing the most pollutants for these small types of events.

10.0 SWAT MODEL APPLICATION (BRADY LAKE WATERSHED)

10.1 DEVELOPMENT OF SWAT MODEL OF BRADY CREEK WATERSHED

10.1.1 Overview of Input Data for SWAT

The ArcGIS-ArcView extension of SWAT was utilized to delineate the watershed into subbasins that correspond to each of the 42 PL-566 dams, Brady Lake dam, and additional points of interest using 10-meter resolution digital elevation model (DEM) data obtained from Geo Community (2011). The delineation of the Brady Creek watershed into subbasins is depicted in Figure 39.

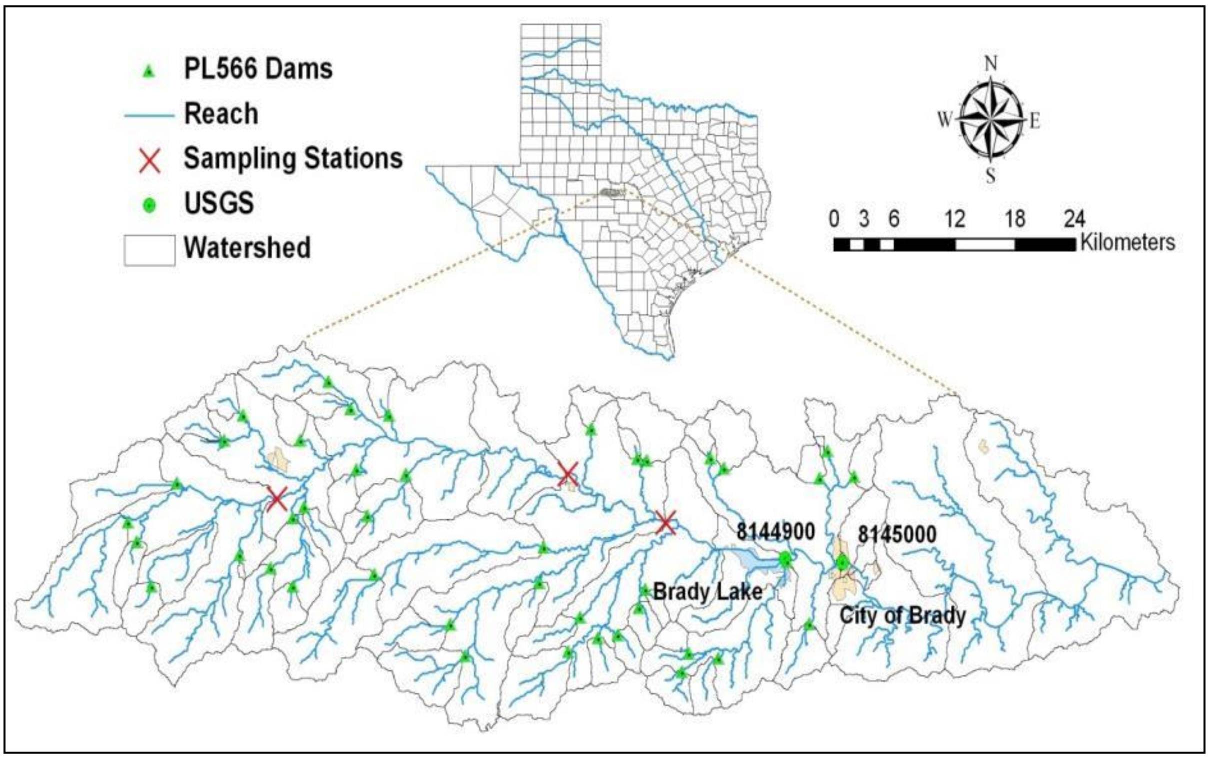


Figure 39 **Map of Brady Creek watershed with PL-566 reseroirs, Brady Lake, USGS stations and SWAT delineated subbasins**

Additional data input needs for operating SWAT included geographic information system (GIS) layers of land use and soils, and also weather data. The land use and land cover GIS were acquired from USGS web page for Concho, McCulloch, San Saba, Menard, and Mason Counties (USGS, 2011) representing the 2006 National Land Cover Data (Figure 40 and Table 18). By far the dominate land use in the watershed is range with brush (81.8%), and other categories of secondary importance exceeding 2 percent in coverage included range with grasses dominating (4.5%), low-density residential (3.9%), evergreen forest (3.3%), and row crop agriculture (2.7%).

The GIS soils data required by SWAT were downloaded from Natural Resources Conservation Service (NRCS), Soil Survey Geographic (SSURGO) soil data mart web page for Concho, McCulloch, Menard, and San Saba counties (NRCS, 2011). Weather information required by

SWAT (i.e., precipitation and temperature) was available for January 1, 1939 through December 31 2011 at four precipitation stations and one temperature station (Table 19; NCDC, 2011b).

An additional effort on model input was required in order to properly include the 42 PL-566 reservoirs in the SWAT model of Brady Creek watershed. Characteristics of each reservoir regarding conservation pool storage and flood storage were obtained from the Texas State Soil & Water Conservation Board (TSSWCB, 2011). An example of several of the key input parameters to characterize one PL-566 reservoir is provided in Table 20. Each PL-566 reservoir was characterized in SWAT uniquely based on its descriptive information.

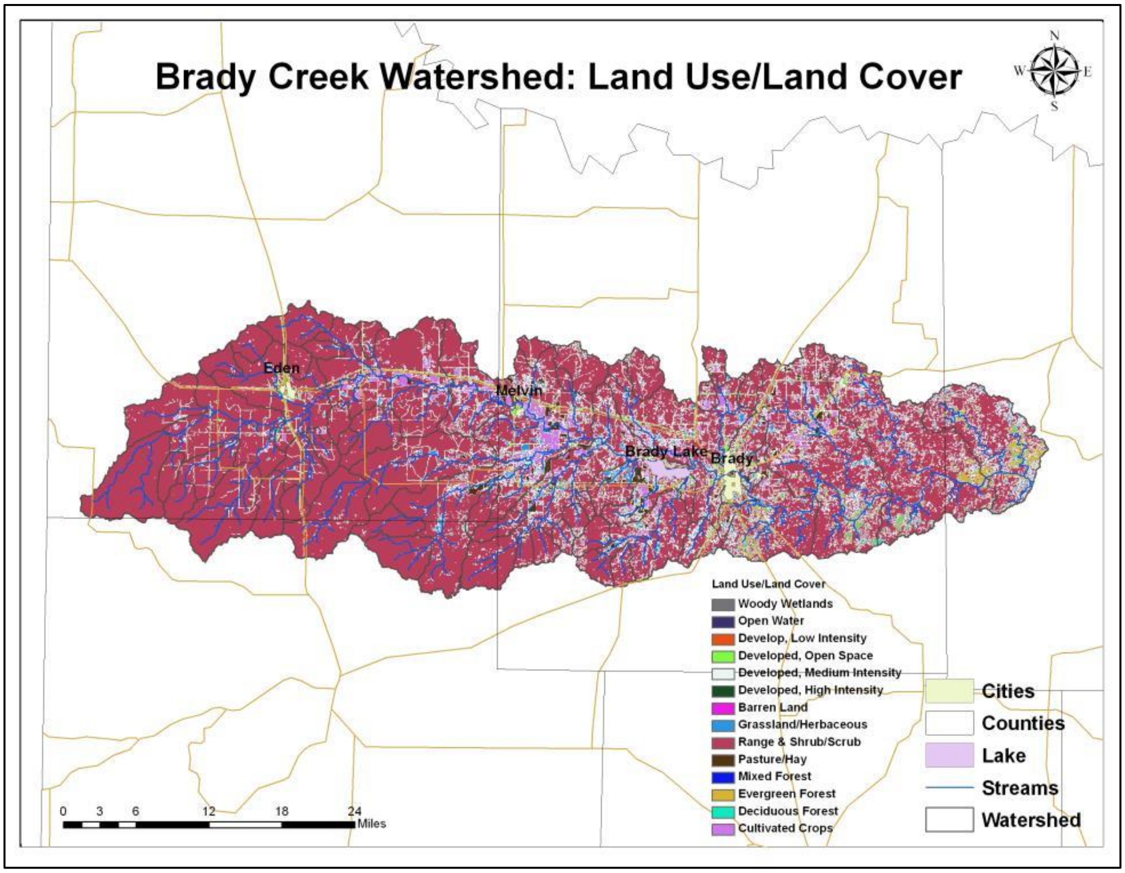


Figure 40 **Land use of Brady Creek watershed**

Table 18 **Summary of Land Use and Land Cover for Brady Creek watershed**

Land Use (NLCD 2006)	Area (ac)	Percent (%)
Water	1,788	0.3%
Residential-Low Density	20,039	3.9%
Residential-Medium Density	1,586	0.3%
Residential-High Density	384	0.1%
Industrial	177	0.0%
Forest-Deciduous	8,256	1.6%

Land Use (NLCD 2006)	Area (ac)	Percent (%)
Forest-Evergreen	16,806	3.3%
Forest-Mixed	30	0.0%
Range-Arid	62	0.0%
Range-Brush	420,400	81.8%
Range-Grasses	23,111	4.5%
Hay	7,423	1.4%
Agricultural Land-Row Crops	13,685	2.7%
Wetlands-Forested	3	0.0%
Total	513,812	100.0%

Table 19 Summary of precipitation and air temperature data for station used to develop SWAT input

Variable	Location	Month											
		Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec
Precipitation (mm)	Brady	33.3	42.7	38.7	62.1	82.9	64.5	41.7	60.0	71.3	73.4	40.9	30.8
	Rock	29.1	35.2	37.3	57.1	84.7	65.3	37.3	61.3	73.7	72.3	35.2	24.6
	Eden	30.4	36.1	36.3	57.7	80.8	69.1	41.5	65.6	76.9	69.1	37.6	24.5
	Menard	27.7	34.7	37.3	56.7	76.8	66.3	41.7	60.4	69.1	72.8	33.9	23.3
Temp. (C°)	Brady	7.45	9.70	13.59	18.39	22.45	26.14	28.00	27.85	24.22	18.96	12.83	8.53

Units of measurement are the same as used SWAT input; Period of record: January 1, 1939 to December 31, 2010, Source: NCDC (2011b)

As with the previously discussed QUAL2K and SWMM models, confidence in predictions from SWAT are improved through a verification process that uses measured data for comparison to SWAT prediction. For the Brady Creek watershed the verification data consisted of hydrologic data from the two USGS gages in the watershed and water quality data collected at stream location in the watershed of Brady Lake.

10.1.2 Overview of Measured Data for SWAT

Storage volume data for Brady Lake (USGS Gage 08144900) and streamflow data at City of Brady (USGS Gage 08145000) were available (see gage locations of Figure 39). USGS gage streamflow data covered the periods from June 1, 1939 to September 30, 1986 and then from May 2001 – December 2011. USGS reservoir storage volume data covered the periods from May 1, 1963 to January 16, 1984 and then from January 20, 1999 – November 9, 2011.

Regarding measured water quality data for model verification, three stations with TCEQ identifiers were located in the watershed above Brady Lake with some water quality data:

- Station 17347: Brady Creek at unnamed road west of Brady and upstream of Brady Lake,

- Station 20406: Brady Creek at US Highway 83 south of Eden, and
- Station 20409: Brady Creek R RR 2028 north of Melvin (Figure 39)

For the application of SWAT, the water quality parameters considered from these stations were TSS, TN, and TP.

Table 20 Example of typical SWAT input to describe a PL-566 reservoir

Parameter	Value
Subbasin location for reservoir	19
Month reservoir became operational	6
Year reservoir became operational	1957
Reservoir surface area at emergency spillway (ha)	149.6
Reservoir volume at emergency spillway (10^4 m^3)	356.9
Reservoir surface area at principal spillway (ha)	21.4
Reservoir volume at principal spillway (10^4 m^3)	17.9
Average daily principal release rate (m^3/s)	2.8

Data provided is for the PL-566 reservoir in Subbasin 19

10.2 SWAT MODEL VERIFICATION

The SWAT model of the Brady Creek Watershed was verified against measured data in sequential steps of first streamflow and then in a second step for the water quality parameters of TSS, TN, and TP.

10.2.1 Verification of SWAT to Streamflow

The verification of streamflow predictions by the Brady Creek watershed SWAT model was fraught with challenges as follows. Since the SWAT applications to address stakeholder interests involved a focus on the Brady Lake watershed, the verification process was directed to the predictive capabilities of the model for the watershed of the reservoir.

Separate calibration and validation periods were selected for the streamflow verification process. Initially, the approach was to use USGS Gage 0814500 daily streamflow record for the pre-Brady Lake dam period, which included June 1, 1939 through April 30, 1963. This period provided a period of recorded streamflow data without the presence of Brady Lake to intercept much of the flow. However, an exerted effort involving multiple operations of SWAT for this period could not result in a model that performed near any of the statistical model performance goals provided in the QAPP. The main challenge appeared to be the extreme and prolonged drought that occurred in the 1950s. A single set of SWAT input parameters could not be found that provided acceptable streamflow results for both the period of drought and also for the pre- and post-drought periods.

There were also some concerns with using 2006 land use data to represent watershed conditions during the 1940s and 1950s, and changes in land use may have been an undetermined part of the difficulties with model calibration.

Therefore, of necessity the approach taken was to calibrate the model to the post-dam period from May 1963 through December 1983 and to validate the model to the period from May 2001 through December 2010. At the time the SWAT model development began, the last full year of precipitation and air temperature data required as input to SWAT was for the year 2010, which determined the ending date of model operation. The periods selected for calibration and validation reflect the dates when the USGS streamflow and reservoir water-level gages were both operating. The Brady Creek streamflow record of Gage 0814500 included June 1, 1939 to September 30, 1986 and then May 2001 – December 2011, and the Brady Lake water level and storage volume record of Gage 08144900 included May 1, 1963 to January 6, 1984 and then January 20, 1999 to November 9, 2011.

Because SWAT application would focus on the Brady Lake watershed and SWAT predicted flows would be used as input to the model of Brady Lake, the preference was to calibrate and validate the model for flows that included the inflows to the reservoir. An alternative would have been to calibrate the model to the recorded streamflows at Brady Creek gage, which would have effectively been calibrating the model only to the drainage area between the gage location and the Brady Lake dam. The alternative calibration approach had some appeal but was dismissed by the modelers because the model would not be calibrated to the area of greatest interest and interpretation of the gaged streamflow record was complicated during the wettest periods by uncontrolled releases from Brady Lake.

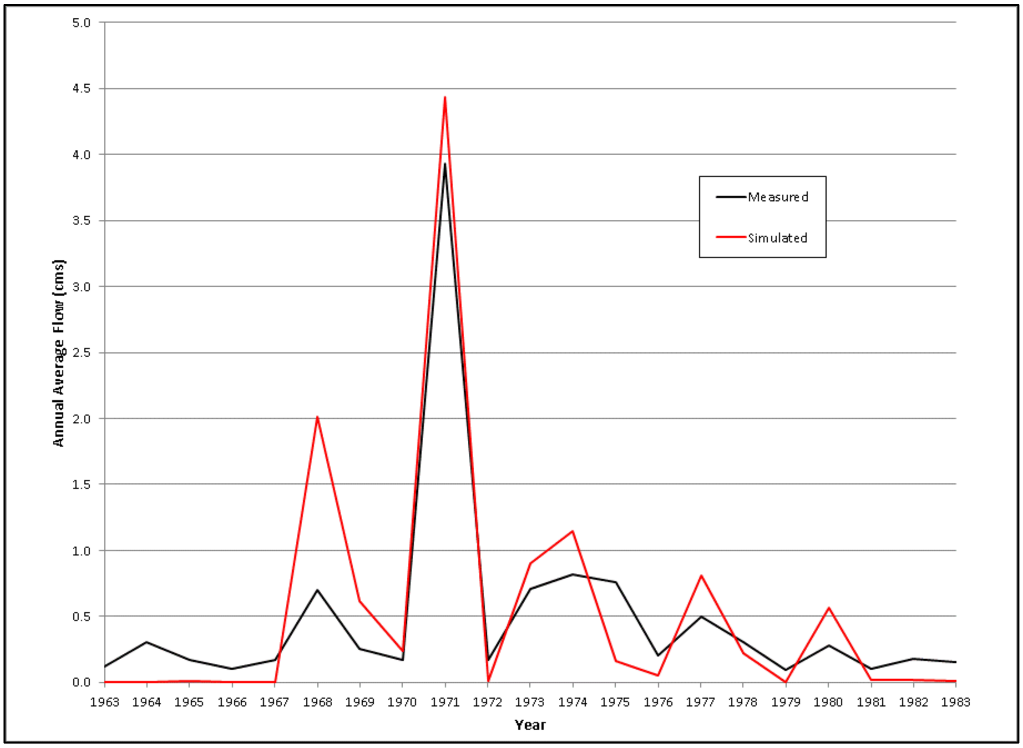
Though not optimal, but in the absence of a streamflow gage above Brady Lake, the approach taken was to focus on monthly and annual predictions by SWAT at the USGS streamflow gage, which is located on Brady Creek in the City of Brady and below Brady Lake, and to add to the gaged flows an estimate of the flow being intercepted by Brady Lake. An Excel spreadsheet was developed to perform a water mass balance that included gaged monthly changes in storage volume, surface area estimates and the net of precipitation and evaporation, whereby an estimated inflow to the reservoir was computed for each month of the separate calibration and validation periods. These estimates of monthly inflows were added to a monthly aggregation of daily streamflow record from the Brady Creek streamflow gage, with additional corrections necessitated during those few periods when the reservoir was known to be releasing flows. The computed monthly flow represented an estimated monthly streamflow to be used in comparison with SWAT monthly streamflow predictions. Under this approach, the Brady Creek adjusted flows represent an estimate of the flows if Brady Lake were not present. Therefore, during the calibration and validation steps SWAT was operated with the operation of Brady Lake suspended through adjustment of the appropriate model input. The streamflows computed in this manner are loosely defined as measured data in the subsequent tabular and graphical results. Though this approach introduces additional uncertainty through the need to estimate monthly inflows to Brady Lake, it gains the significant benefit of allowing the verification of SWAT streamflows predicted for the entire Brady Lake drainage area and not just the predicted flows for the intervening drainage area between Brady Lake and the downstream USGS gaging station within the City of Brady.

The calibration process for the streamflow predictions by SWAT entailed adjustments of parameters in Table 21, which reflects the final values used in the model. The adjustment of each parameter was restricted to the range of acceptable values. The value of 0.363 for APLHP_BF was determined using baseflow separation program (Arnold et al., 1999; Arnold and Allen, 1995) with measured daily flows for January 1, 1942 to April 31, 1962 years that are prior to the initiation of operation of Brady Lake dam.

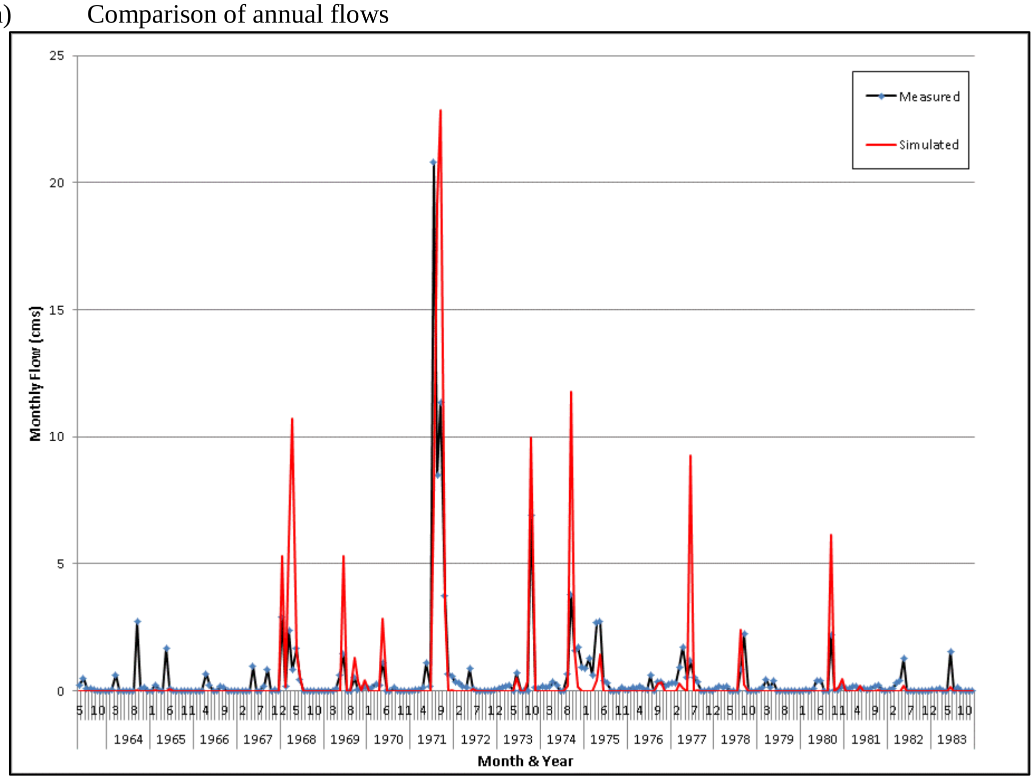
Table 21 SWAT hydrology calibration parameters and final values

SWAT Parameters	Calibration Value
Initial SCS CN II	Decreased by 5 units
Daily curve number calculation method (ICN)	1
Plant ET curve number coefficient (CNCOEF)	1.0
Potential Evapotranspiration (PET) method	Hargreaves
Baseflow alpha factor (ALPHA_BF)	0.363 days
Threshold depth of water in the shallow aquifer (GWQMN)	1,250 mm
Groundwater delay (GW_DELAY)	31 days
Deep aquifer percolation fraction (RCHRG_DP)*	0.6
Soil evaporation compensation factor (ESCO)	0.8
Surface runoff lag coefficient (SURLAG)	0.6
Groundwater "revap" coefficient (GW_REVAP)	0.2

The results of the streamflow calibration are depicted at annual and monthly time scales in Figure 41. The model was directionally correct in response with correspondence of higher simulated flows generally tracking higher measured flows, though the model suffered from under predictions during low flow periods and over predictions during periods of high flow. The goal of simulated annual flows being within +/-20 percent of the measured data was not realized, though the average flow over the entire calibration period was reasonably predicted (Table 22).



a) Comparison of annual flows



b) comparison of monthly flows

Figure 41 Comparison of measured streamflow and SWAT simulated streamflow for the calibration period of 1963-1983

Table 22 Comparison of measured and simulated annual average flows for the calibration period of 1963-1983

Year	Measured (cms)	Simulated (cms)	Percent Difference
1963	0.121	0.001	-99.3%
1964	0.304	0.001	-99.5%
1965	0.175	0.008	-95.6%
1966	0.103	0.001	-99.2%
1967	0.174	0.001	-99.2%
1968	0.701	2.014	187.4%
1969	0.256	0.618	141.1%
1970	0.169	0.236	40.2%
1971	3.932	4.438	12.9%
1972	0.167	0.007	-95.9%
1973	0.712	0.902	26.8%
1974	0.816	1.150	41.0%
1975	0.756	0.158	-79.0%
1976	0.202	0.052	-74.3%
1977	0.497	0.810	63.0%
1978	0.307	0.218	-29.0%
1979	0.098	0.001	-98.9%
1980	0.283	0.565	100.1%
1981	0.106	0.019	-82.2%
1982	0.182	0.019	-89.8%
1983	0.158	0.014	-91.1%
Average	0.487	0.535	9.9%

Note that the year 1963 is a partial year beginning in May

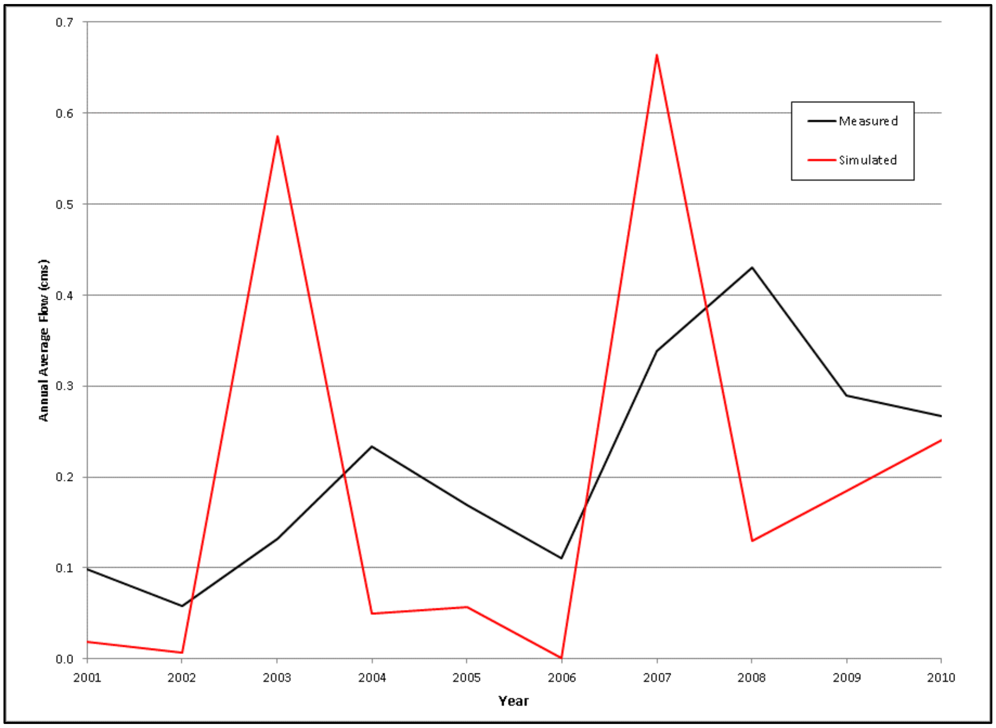
For model validation, SWAT was operated for the period of May 2001 through December 2010. For the validation period, the input parameters to SWAT were kept at the calibration values (e.g., Table 21) except for those time dependent inputs of precipitation and air temperature. The simulated results for the validation period indicated a similar response to that of the calibration period (Figure 42). The model was directionally responsive when compared to the measured data, but again generally over predicted high flow periods and under predicted low flow periods. In the same manner as the calibration, the validation results failed the goal of annual values being within +/-20 percent of measured data, but across the validation period the average simulated flows were acceptably predicted (Table 23).

The verification process of the SWAT model of Brady Creek watershed emphasizing the drainage area of Brady Lake showed that the model was directionally correct in response to precipitation, but lacking in accuracy at both the monthly and annual time scales. Some, though not all of the differences, between measured and simulated flows can be attributed to the need to estimate inflows to Lake Brady based on a simple water balance approach in order to compute the total flow at the Brady Creek streamflow gage if the reservoir were not in place. Fortunately, while the model was lacking in the desired accuracy on an annual basis, flows were well simulated over the long term being over predicted by only 10 percent during the calibration period and under predicted by 9 percent during the validation period. While the capabilities of the SWAT model to predict flow cannot be considered strong or at the level initially desired, the model is directionally correct in its flow predictions, and over the long-term of multiple years, the average flow is well replicated. Based on the strength of the long-term predictions, SWAT flow predictions were considered adequately verified for the intended purposes of this project, i.e. the evaluation of hydrologic changes relative to brush control and conditions with and without the presence of PL-566 reservoirs in the Brady Lake watershed. It was also considered adequately verified to provide inflow inputs for modeling TDS in Brady Lake.

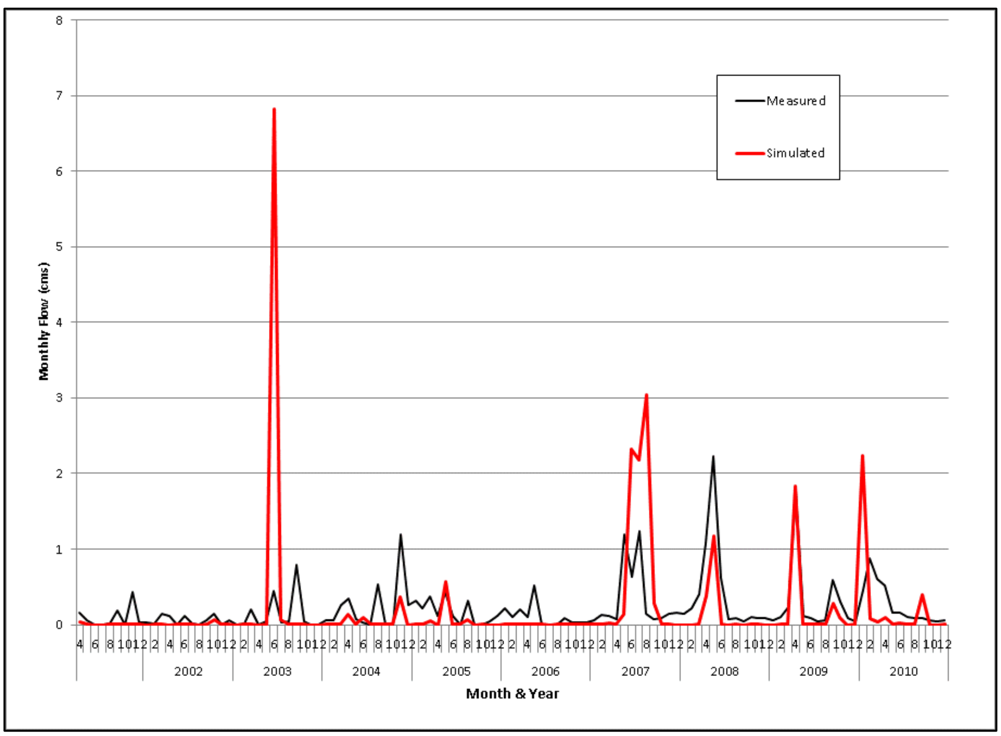
Table 23 Comparison of measured and simulated annual average flows for the validation period of 2001-2010

Year	Measured (cms)	Simulated (cms)	Percent Difference
2001	0.0983	0.0189	-80.8%
2002	0.0580	0.0066	-88.6%
2003	0.1327	0.5740	332.7%
2004	0.2329	0.0503	-78.4%
2005	0.1688	0.0575	-65.9%
2006	0.1106	0.0012	-98.9%
2007	0.3387	0.6645	96.2%
2008	0.4302	0.1300	-69.8%
2009	0.2898	0.1846	-36.3%
2010	0.2672	0.2408	-9.9%
Average	0.2127	0.1928	-9.4%

Note that year 2001 is a partial year beginning in May.



a) Comparison of annual flows



b) Comparison of monthly flows

Figure 42 Comparison of measured streamflow and SWAT simulated streamflow for the calibration period of 2001 - 2010

10.2.2 Verification of SWAT to Water Quality Parameters

Measured TSS, TN, and TP were available from limited sampling performed in 2008 and then from 2010 through 2012 at Stations 17347, 20406, and 20409 in the Brady Creek watershed above Brady Lake. Over this period the number of data values by station for TSS, TN, and TP were 12 at Station 17347, 19 at Station 20406, and 19 at Station 20409. The amount of water quality data at these stations is insufficient for a thorough evaluation of SWAT, but this was recognized as a likely occurrence when the goals of a successful verification were established in the QAPP. The stated goals for calibration and validation of TSS, TP, and TN concentrations were that the means of predicted values fall within two standard deviations of the mean of the observed concentrations that occurred within the selected simulation period. A more thorough and rigorous verification process for SWAT would necessitate much more data than was available to this project and a means of describing the time history of flow at these locations.

Because some of the measured data were collected beyond the ending date of December 31, 2010 for which SWAT was operated, this had to be accounted for in the verification process. The approach taken was to combine the calibration and validation steps into one step and to determine the SWAT predictions at these stations for the simulated period of 2008 – 2010. The comparison of SWAT predictions to measured data were then made based on this approach (Table 24. The measured data are provided for the period of direct comparison with the SWAT predictions (2008-2010) and for the period encompassing the dates of all available data (2008-2012). While the acceptance goal from the QAPP is very broad, the SWAT simulated TN, TP, and TSS did meet the goal when using the entire dataset from 2008-2012. The 2008-2010 measured dataset only contained 5 concentrations for each parameter at each station. SWAT simulations met the required goal without changing any of the input parameters to the model that control water quality. The verification goal was met and there were too few data to justify refinement of model input to improve simulation capabilities. The SWAT model was considered adequately verified for the purpose of intended application which was to compare loadings of TN, TP, and TSS to Lake Brady under conditions with and without PL-566 reservoirs in operation.

Table 24 Comparison of measured and SWAT simulated water quality parameters

Station	Period & Condition	TN Mean (mg/L)	TN Std.Dev. (mg/L)	TP Mean (mg/L)	TP Std.Dev. (mg/L)	TSS (mg/L)	TSS Std.Dev. (mg/L)
17347	2008-2010 Measured	2.66	0.87	0.29	0.16	70	42
	2008-2012 Measured	3.11	2.23	0.51	0.81	77	49
	2008-2010 Simulated	6.35	7.68	0.54	0.54	21	15
20406	2008-2010 Measured	1.42	0.31	0.21	0.27	33	30
	2008-2012 Measured	1.66	1.14	0.25	0.43	158	521
	2008-2010 Simulated	1.32	0.92	0.11	0.01	9	14
20409	2008-2010 Measured	4.79	1.72	0.07	0.01	22	13
	2008-2012 Measured	4.09	2.51	0.12	0.11	24	25
	2008-2010 Simulated	2.21	1.77	0.22	0.14	21	16

10.3 SWAT MODEL SENSITIVITY ANALYSIS FOR FLOW

The sensitivity analysis of SWAT focused on flow predictions because there was too little data under the water quality verification process to justify the analysis for water quality predictions. It would be expected that there is a large uncertainty associated with water quality predictions from SWAT, but fortunately the model application was to give an estimate of the relative benefits (or percent change between conditions with and without PL-566 reservoirs in the watershed) and not absolute benefits of PL-566 reservoirs in reducing pollutant loadings to Brady Lake.

A sensitivity analysis of streamflow was performed that considered three main factors found to be important during the process of model verification to flow. These three factors were the

- GWQMN - the threshold depth the shallow groundwater must reach before contributing to surface flow
- CN - Curve number in the Soil Conservation Service method to predict surface runoff
- RCHRG_DP – fraction of the percolation from the root zone that recharges the deep aquifer.

For the sensitivity analysis, SWAT was operated for the calibration period of 1963-1983 with the parameters varied one at a time and all other parameters held constant. The sensitivity analysis presented in Table 25 confirms that the average streamflow over the calibration period was very sensitive to all three parameters. The sensitivity, however, was nonlinear. Streamflow was more responsive to a decrease in GWQMN and RCHRG_DP than to an increase in these parameters. Conversely, streamflow was more responsive to an increase in CN than to a decrease in its value.

Table 25 SWAT sensitivity analysis of streamflow predictions, 1963-1983 period

Parameter	Baseline Value	Changed Value	Percent Change in Value (%)	Percent Change in Average Flow (%)
GWQMN	1,250 mm	1,500 mm	+20%	-16%
GWQMN	1,250 mm	1,000 mm	-20%	+44%
CN	Final Values	+5 units	+8%	+63%
CN	Final Values	-5 units	-8%	-34%
RCHRG_DP	0.4	0.6	+50%	-9%
RCHRG_DP	0.4	0.2	-50%	+48%

10.4 APPLICATION OF SWAT MODEL OF BRADY CREEK WATERSHED

10.4.1 Evaluation of PL-566 Reservoirs

The purpose of the SWAT evaluation of the PL-566 reservoirs was to determine the benefits being derived to Brady Lake regarding reductions in TSS, TN, and TP loadings into the lake. To evaluate these benefits, the verified SWAT model was operated for a 50-year period to simulate baseline conditions reflecting conditions over recent decades. The baseline condition used the precipitation and air temperature records from 1961 through 2010. (Note: It is recognized that impoundment of water did not begin in Brady Lake until May 1963; however, for this evaluation, the reservoir was assumed to begin impoundment January 1961 in order to provide a 50-year period of simulation.) For the scenario condition to be compared to the baseline condition, the PL-566 reservoirs were not included as input to SWAT, effectively removing these reservoirs from the simulation.

The annual average loadings of TSS, TP, and TN entering Brady Lake under the baseline condition with PL-566 reservoirs and the scenario without PL-566 reservoirs is provided in Table 26. The comparison results indicate that the PL-566 reservoirs effectively reduce sediment loadings to Brady Lake by an estimated 45% and nutrient loadings of phosphorus and nitrogen by about 20%. Based on the limited data for verification of SWAT predictions of water quality parameters, greater reliability should be assigned to the predicted changes in annual loadings than to the actual predicted loadings.

Table 26 SWAT evaluation of effects of PL-566 reservoirs on pollutant loadings to Brady Lake for the 50-year simulated period of 1961-2010

Parameter	Baseline Condition With PL-566 Reservoirs (tons/year)	Scenario Without PL-566 Reservoirs (tons/year	Percent Increase in Annual Loadings
TSS	487	706	45%
TP	31.4	38.0	21%
TN	2.31	2.81	22%

10.4.2 Evaluation of Brush Control

A similar modeling application approach to that used to assess PL-566 reservoirs was employed to evaluate effects of brush control on water yield to Brady Lake. The 50-year period of 1961 to 2010 was simulated with the historical precipitation and air temperature data for that same period. Brady Lake was assumed to be impounding water for this entire period. The baseline conditions were identical to that used for evaluating PL-566 reservoirs, including the land use conditions indicated from the 2006 NLCD (see Figure 40 and Table 18).

Two scenarios were considered to evaluate hydrologic benefits of brush control on inflows to Brady Lake. Both scenarios considered the optimistic situation of 100 percent adoption of brush control on all areas with a land use of Range-Brush in Table 18. The two scenarios differed, however, in the adjustments of SWAT input parameters to reflect changes resulting from brush removal: Because the specific changes to SWAT input required to represent implementation of brush control are based on best professional judgment and not strict scientific experimental results, for this project the decision was to provide a conservative, low increase in water yield scenario (Scenario 1) and a less conservative, high increase in water yield scenario (Scenario 2). These scenarios were designed to bracket, or give an upper and lower limit to water yield increase from a watershed-wide implementation of brush control in the Brady Lake watershed.

Scenario 1: The maximum potential leaf area index (BLAI) value of 2 for RNGB (Range-Brush) in CROP.dat input file to SWAT was changed to 1 to reflect a change to predominately grasses from evasive brush.

Scenario 2: The same change in the value of BLAI was made, and the curve number (CN) governing surface runoff was increased a value of 1 for the Range-Brush land use to reflect both the change to predominately grasses and an assumed commensurate increase in runoff potential.

The changes in annual average surface flow and subsurface flow are provided in Table 26 for the 50-year simulation period. There still remains a need for long-term scientific studies to increase understanding of the benefits of brush control on the hydrologic water balance of a watershed. This application of SWAT was performed as a means of providing estimates of benefits through adjustments of input parameters that could change as a result of brush control. The predicted increases in Table 27 are based on 100 percent adoption of brush control on all range with brush infestation, which was indicated to be a high percentage in the 2006 NLCD land use of the Brady Creek watershed.

Table 27 SWAT predictions of annual average hydrology for baseline and brush control condition Scenarios 1 and 2 for the period of 1961-2010

Parameter	Baseline	Brush Control (Scenario 1)	Brush Control (Scenario 2)
Surface flow (cms)	0.32	0.32	0.37
Surface flow percent change (%)	–	0%	14%
Subsurface flow (mm)	416	426	430
Subsurface flow percent change (%)	–	2%	3%

11.0 WRAP MODEL APPLICATION OF BRADY LAKE

11.1 DEVELOPMENT OF WRAP MODEL OF BRADY LAKE

The modeling system for Brady Lake included the SWAT model to provide initial inflows and the WRAP model for prediction of water volume and salinity in the lake. Because SWAT was previously verified for the Brady Lake watershed, further adjustments to SWAT model were not made in developing the Brady Lake modeling system. The verification process consisted of adjustments to the input of WRAP.

11.1.1 Input Data Requirements for WRAP

The reservoir water and salt balance modeling component of WRAP requires five major input types:

1) water storage and water level description of Brady Lake,
2) monthly inflows to the reservoir,
3) TDS concentrations of the monthly inflows to the reservoirs,
4) monthly net evaporation (gross monthly evaporation minus monthly precipitation), and
5) withdrawals from the reservoir, which in this case are municipal demand from the City of Brady.

To the degree possible, this project took advantage of datasets developed under the State of Texas WAM model for the Colorado and Colorado-Brazos Coastal Basins as maintained on a TCEQ website (TCEQ, 2012). The existing WAM model contained the needed input to describe the storage volume and surface area conditions of Brady Lake (Table 28).

Table 28 Storage volume and surface area conditions used to describe Brady Lake up to conservation pool

Storage Volume (ac-ft)	Surface Area (ac.)
0	0
960	160
2,060	285
2,900	360
5,200	575
6,690	710
8,650	860
10,960	1,015
16,910	1,370
20,700	1,560
24,740	1,765
30,431	2,020

SWAT predicted daily inflows aggregated to monthly values were used as the initial inflow input to the Brady Lake WRAP model. As will be discussed in more detail in the WRAP model verification that follows, the SWAT inflows required further adjustments to allow WRAP to reasonably predict measured reservoir volumes.

The TDS concentrations of monthly inflows to the reservoir were based on the measured TDS data for Station 17347 on Brady Creek above Brady Lake; the most downstream station on Brady Creek located above Brady Lake. The 15 TDS measurements collected at this station from 2001 through 2012 were used to provide general guidance on the anticipated variability of TDS with streamflows into Brady Lake. These data, however, were too sparse to allow development of a statistically meaningful relationship of TDS to streamflow for Station 17347. TIAER and UCRA collaborated in using these limited data to develop the monthly TDS concentrations required in WRAP input. These inputs then required additional adjustment through the calibration process.

The net evaporation input was obtained from the WAM database for the Colorado and Colorado-Brazos Coastal Basins full authorization condition (TCEQ, 2012).

Finally, withdrawals by the City of Brady were obtained by UCRA from the city and provided to TIAER. The data consisted of the monthly withdrawals for the City of Brady water treatment facility that occurred during the period of October 2006 through 2011. Prior to October 2006 the City of Brady did not utilize its water rights and did not make any withdrawals from Brady Lake.

11.1.1 Verification Data Requirements for WRAP

To verify the WRAP model, two sources of data were used. The daily data from the USGS gage on Brady Lake (Station 08144900) was used for validating the SWAT/WRAP modeling system predictions of Brady Lake storage volume. USGS Gage 08144900 provided data for end-of-month storage volume for the periods of March 1963 through December 1984 and January 1999 through December 2010. The gage was inoperative between these two periods of record.

Verification of WRAP model predictions of TDS were made by comparison to the measured data at TCEQ Station 12179 on Brady Lake. The water quality data for this station were obtained from the TCEQ SWQMIS database. This station contained measurements collected beginning March 1975, and data from that beginning date through October 2010 were used in the validation process.

11.2 VERIFICATION OF WRAP

The verification process for the WRAP Brady Lake model combined the calibration and validation steps. The reason for combining the calibration and validation steps resulted from greater than anticipated difficulties in getting WRAP to reasonably predict Brady Lake storage volumes using SWAT inflows as input. While SWAT predictions of flow met long term averages, the predictions were lacking on both a month-to-month basis and year-to-year basis. Consequentially, when SWAT inflows were used in WRAP, poor predictions of reservoir storage volumes occurred.

During the validation process, a regression equation was developed to relate SWAT predicted monthly inflow volumes to those inflows required to provide good predictions of Brady Lake storage volumes by WRAP. The optimal regression equation used data from both periods of recorded USGS reservoir volume data. This regression equation approach was driven by the aforementioned difficulties in using unaltered SWAT flow predictions in WRAP and the need to have some means of using SWAT inflows to predict Brady Lake reservoir volume during the period of 1984 -1998 when the USGS gage was inoperative and there was no measured reservoir volume data. Through this regression approach that adjusted SWAT inflows, WRAP was able to be operated to provide reasonable predictions of the end-of-month storage volumes of Brady Lake (Table 29 and Figure 43). In Table 29 the results are provided separately for the two different periods of operation of the USGS gage. As indicated in both Table 29 and Figure 43, WRAP predictions were better for the January 1999-December 2010 period than the May 1963-December 1983 period.

Table 29 Brady Lake storage volume validation results using WRAP with adjusted SWAT inflows

Period	May 1963 – December 1983			January 1999 – December 2010		
Reservoir Condition	Measured Volume (ac-ft)	Simulated Volume (ac-ft)	Simulated as Percent of Measured	Measured Volume (ac-ft)	Simulated Volume (ac-ft)	Simulated as Percent of Measured
Average	17,868	15,557	87%	16,773	16,717	100%
Minimum	45	1,127	250%	7,499	8,261	110%
Maximum	34,357	29,996	87%	29,558	29,996	101%

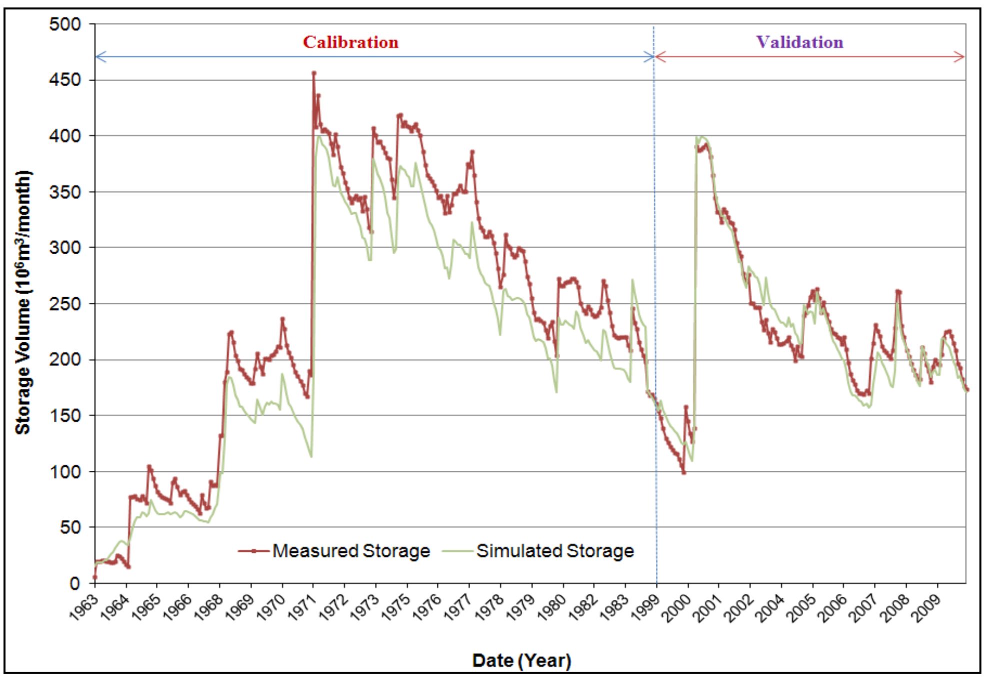


Figure 43 Measured and simulated end-of-month storage volume in Brady Lake for the two periods of measured data.
(Note that the storage volume for this graph is in millions of cubic meters instead of ac-ft.)

The verification goal for reservoir storage volume was for the annual change to be simulated within +/-20 percent of measurements. The WRAP model using adjusted SWAT inflows largely achieved this goal as shown in Figure 44, though for the period from 1963 to 1983 there was a trend of the model under predicting Brady Lake storage volume, which was not indicated for the 1999-2010 period. Based on the verification goal and visual comparisons of measured and predicted storage volumes, the WRAP Brady Lake model was considered to operate adequately for predicting storage volume of the reservoir.

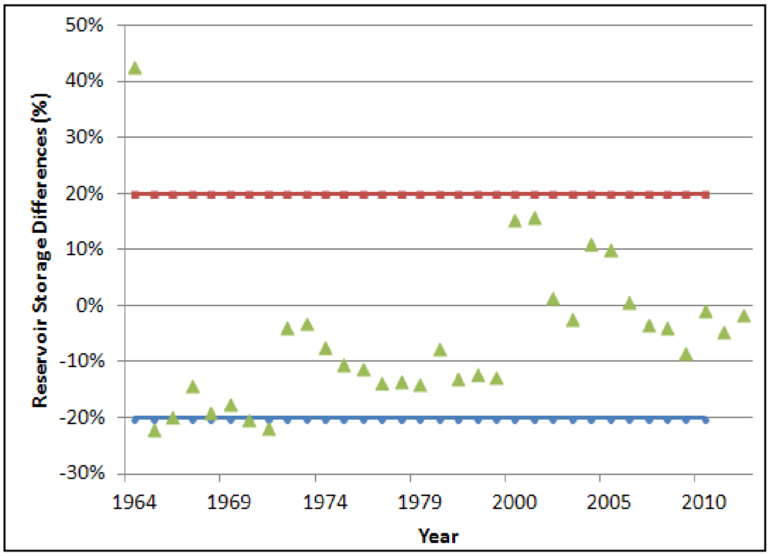


Figure 44 Percent difference between annual (end of December) measured and simulated Brady Lake storage volumes

The second phase of the model validation process was performed to test the performance of the WRAP Brady Lake model in predicting TDS. For the validation of the model to TDS, the monthly inflows were used as developed from the validation process for reservoir storage volume. Separate calibration and verification steps were used for TDS.

To describe the TDS concentrations of the inflows, adjustments to the assumed inflow TDS concentrations were made during the calibration process with the adjustments constrained by the limited measured TDS data. While ideally, there would have been sufficient data to develop a relationship of TDS to inflows, in practice there was insufficient data to develop a statistically meaningful relationship over the range of inflows required. Instead, the approach was to specify a high inflow TDS concentration for months of low inflow, which was defined as monthly inflows less than 100 ac-ft, and a low inflow TDS concentration for monthly inflows greater than or equal to 100 ac-ft. Acceptable results were obtained during the calibration process with this specification of inflow TDS concentrations:

- Monthly inflows < 100 ac-ft, then TDS = 850 mg/L
- Monthly inflows ≥ 100 ac-ft, then TDS = 265 mg/L

TDS concentrations were calibrated so that the mean of predicted values agreed with the mean of measured values within +/-30% and the range in predicted values and measured values agreed within +/-30% according to the calibration goals of the modeling QAPP (UCRA & TIAER, 2012). The calibration results are provided in Table 30 and Figure 45.

Table 30 Comparison of measured and simulated TDS for Brady Lake

	Calibration (03/1975-09/1983)			Validation (01/1999-12/2010)		
	Measured (mg/L)	Predicted (mg/L)	Percent Difference	Measured (mg/L)	Predicted (mg/L)	Percent Difference
Average	870	966	+11%	1,202	1,235	+3%
Min	461	578	+25%	980	774	-21%
Max	1,280	1,629	+27%	1,518	1,813	+19%

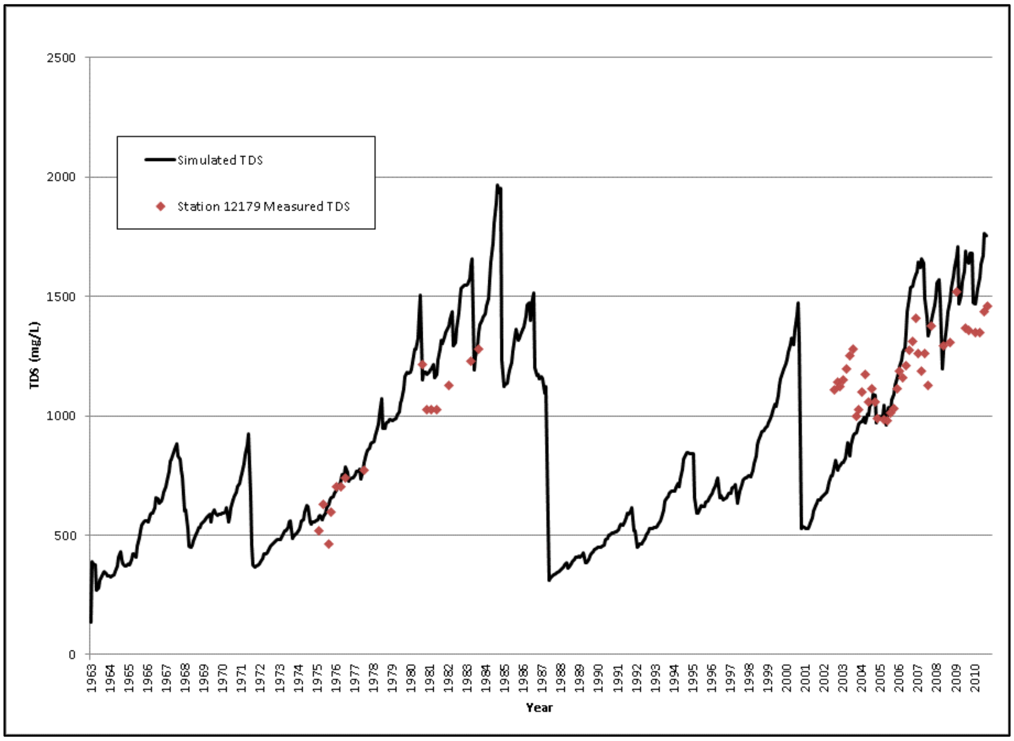


Figure 45 Comparison between measured and simulated Brady Lake TDS

For the verification period of 1999-2010, the WRAP model was operated with the monthly inflows developed during the validation of the model to reservoir storage volume and with inflow concentrations of TDS as developed in the calibration. The results of the TDS verification are provided in Table 30 and Figure 45. The TDS predictions during the verification period also met the QAPP specified goals, though in general the range of predicted values was not as well produced as the range for the calibration period.

From the separate verification steps for Brady Lake storage volume and TDS, it was concluded that the WRAP Brady Lake model operated with SWAT adjusted inflows was able to reasonably predict both storage volume and TDS. Based upon the acceptable verification results, the SWAT and WRAP modeling system of Brady Lake was considered acceptable for applications to evaluate evaporative losses and pumping of WWTF effluent into the lake.

11.3 APPLICATION OF SWAT AND WRAP TO BRADY LAKE

11.3.1 Evaluation Of Evaporative Losses On Brady Lake TDS

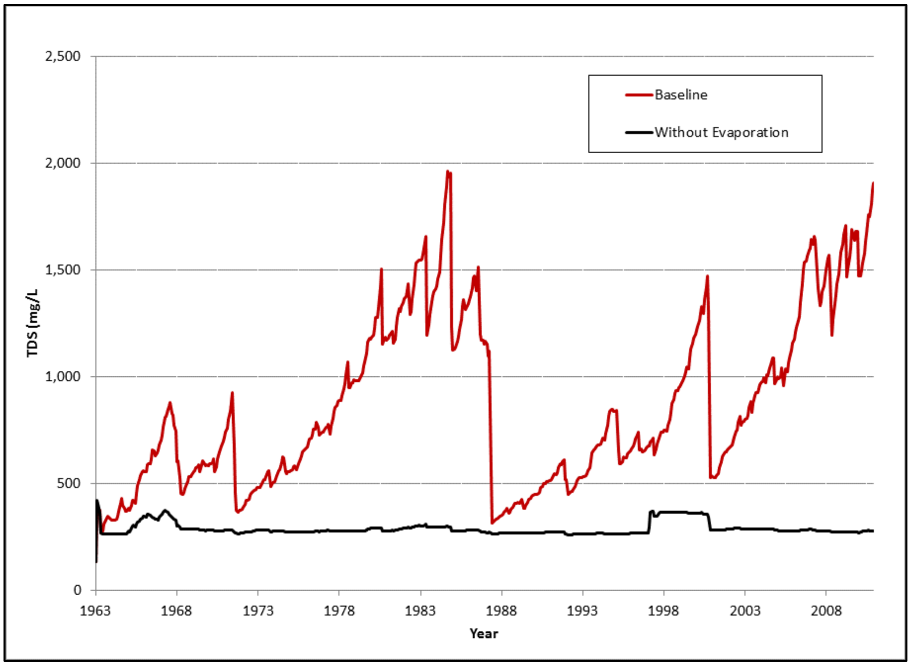
The verified SWAT/WRAP modeling system was applied to evaluate the impact of evaporation on salinities in Brady Lake using TDS as the measure of salinity. The modeling system was operated for the period of 1963-2010 for the baseline condition reflecting existing conditions and for a scenario where the influences of evaporative losses were removed from the input to WRAP. For the scenario condition without evaporative losses, the TDS predicted in the lake was a response only to the TDS assumed in the inflows without the concentrating effects from evaporative losses. The scenario without evaporative losses was performed to maintain reservoir storage volumes at the same amounts as predicted in the baseline condition. To maintain the storage volume, but to eliminate the concentrating effects of evaporative losses, a withdrawal was created for the scenario where the amount of withdrawal on a monthly basis exactly matched the volume of water removed from the reservoir by net evaporation on that same month and the positive net evaporation values were set to zero in the net-evaporation input file. If the net evaporative loss for a month was a negative number, indicating precipitation exceeded gross evaporation for that month, then the withdrawal was set to zero and the net evaporation input file retained the negative value. Thus the evaporation input file would have a zero value for months with net positive evaporation but negative values remained in the input file unchanged, and monthly withdrawals were created as input to WRAP equal to the amount of net evaporation.

Comparisons of predicted WRAP results for baseline and the scenario without evaporative losses are provided for both TDS and reservoir storage volume on Figure 46. The predictions clearly show a major component of the increasing TDS trends in Brady Lake could be associated with evaporative losses that compound the somewhat elevated TDS concentrations of reservoir inflows. The inverse relationship of simulated monthly TDS under the baseline condition to reservoir storage volume can be visually observed by comparing the two time-series graphs in Figure 46. During baseline periods of rapid rise in reservoir storage (e.g., around year 1972) and periods of releases from the reservoir when inflows result in storage volume exceeding the conservation pool elevation (e.g., around year 1988), the baseline TDS responds with a sharp decrease due to dilution from inflows. Conversely, during conditions of declining reservoir storage volume, TDS concentrations increase. In contrast, the predicted TDS in Brady Lake with evaporative losses removed indicated little fluctuation of salinity regardless of reservoir storage volume.

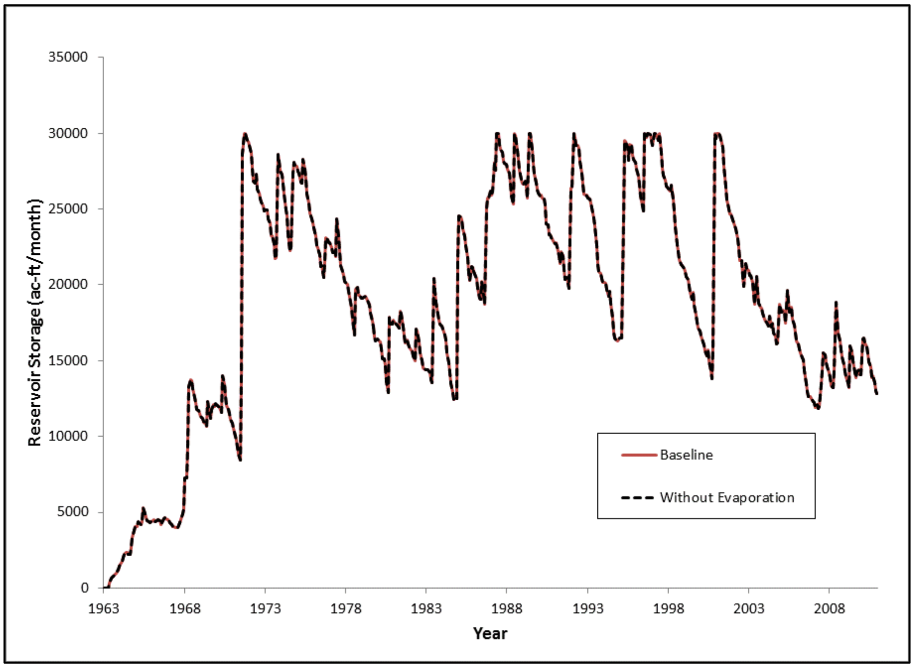
11.3.2 Evaluation Of Effects Of Brady WWTF Effluent On Brady Lake

To evaluate the impact of pumping the effluent from the City of Brady WWTF into Brady Lake, two different pumping conditions were considered:

- Pumping allowed 12-month per year (January – December), and
- Pumping constrained to the five months of November – March, when the effluent is not pumped to supplement flows in Urban Brady Creek under the previously discussed modeling effort to evaluate depressed DO (Chapter 4).



a) Predicted TDS concentrations in Brady Lake



b) Predicted reservoir storage in Brady Lake

Figure 46 **Predicted TDS and storage volumes for Brady Lake for May 1963 through December 2010 under the baseline conditions and the scenario without evaporative losses**

Under both of these pumping conditions, two different TDS concentrations were considered for the WWTF effluent:

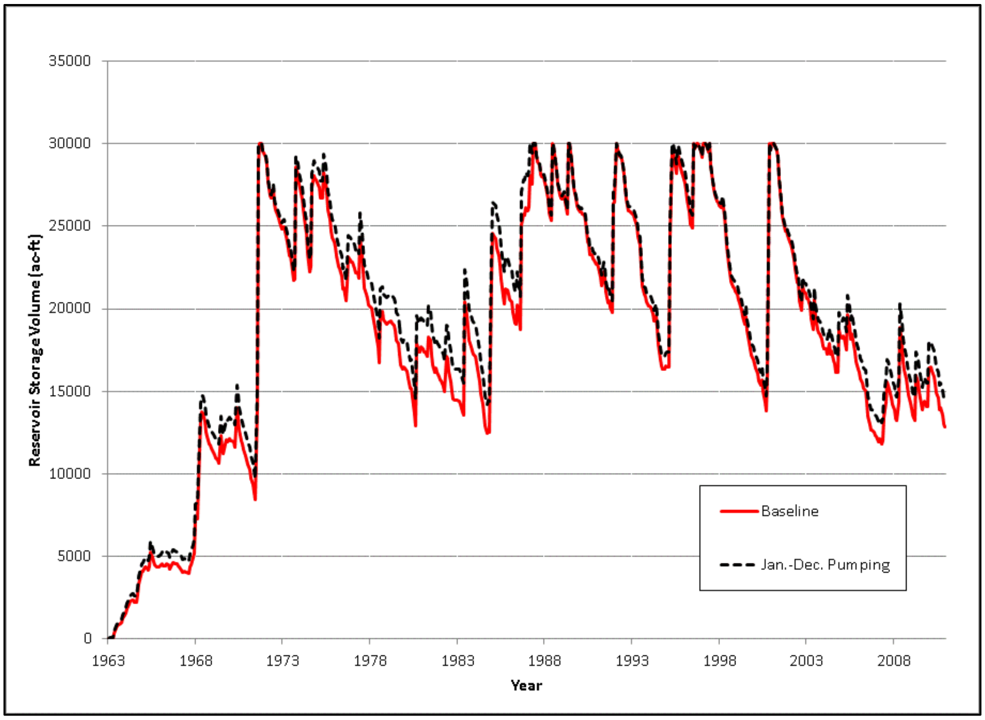
- TDS of 500 mg/L, and
- TDS of 1,000 mg/L.

Measured data on the actual TDS concentrations of the WWTF effluent were not available. Since the municipal water supply of the City of Brady is a blending of groundwater and surface water from Brady Lake, the TDS of the effluent was an unknown that may require further investigation if pumping of the effluent remains a viable option.

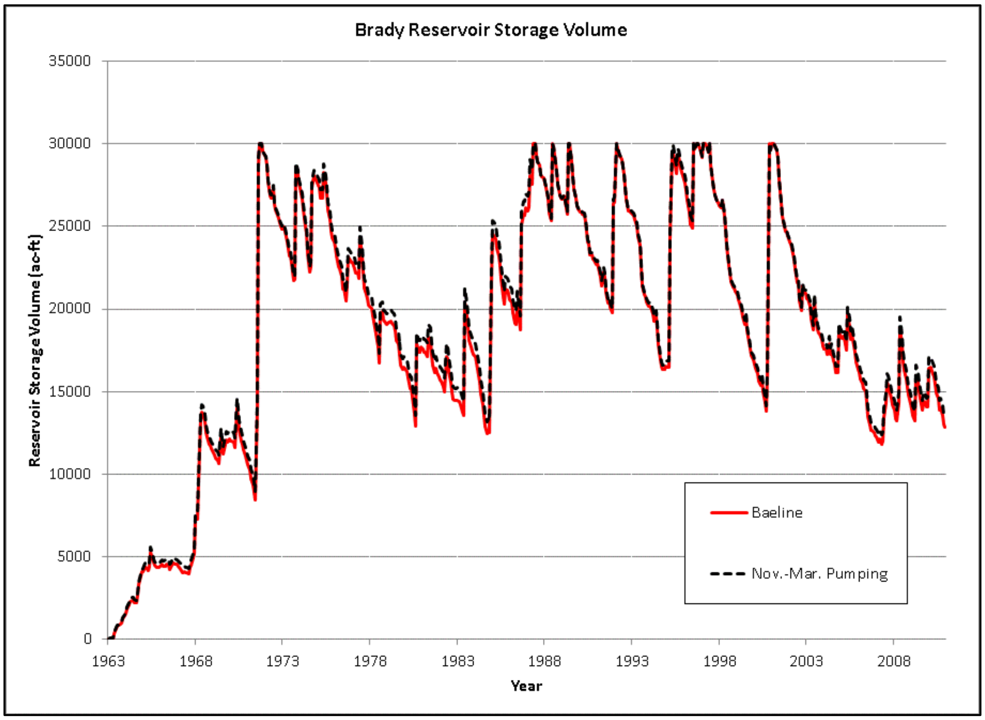
It was assumed that the effluent was pumped to the reservoir at a constant 30 acre-feet (ac-ft) per month. This rate or monthly volume of discharge from the WWTF was the mean flow of 0.27 MGD obtained from the USEPA ECHO data for the period of July 2009 – June 2012. The discharge information contained in the USEPA ECHO database reflected the Discharge Monitoring Report data (or self-reporting data) provided by the City of Brady for the WWTF.

As for the evaluation of evaporative losses scenario, the baseline condition and WWTF effluent scenarios were simulated in WRAP for the period of May 1963 – December 2010. The WRAP simulated results for reservoir storage volume comparing the two pumping scenarios to the baseline condition are provided in Figure 47 and Table 31. The results indicate that if effluent were pumped 12-months per year, the average reservoir storage over the simulated period would increase 5 percent. If the pumping is constrained to the months of November through March when effluent would not be used to enhance flow in Urban Brady Creek for the benefit of instream DO, the benefit to storage was reduced to 2 percent. These results indicate that some benefit to Brady Lake storage volume can be realized through pumping of the Brady WWTF effluent into the reservoir. In Figure 47 more detail on the temporal pattern of changes in reservoir storage are shown indicating that during extended periods of low inflow (e.g., 1975-1988) the greatest benefits to storage are realized and that immediately after periods of releases from the reservoir those benefits are minimal (e.g., 1988-2000).

Since it would be expected that the TDS of the Brady WWTF effluent would be greater than the TDS of the municipal water provided to the city, the effect of the effluent on Brady Lake was also evaluated through WRAP. For both pumping scenarios, effluent with TDS concentrations of 500 mg/L and 1,000 mg/L were considered. The predicted impacts on TDS are provided in Table 32. The predicted results indicated that for both pumping scenarios, if the effluent TDS was 500 mg/L, then the change in Brady Lake average TDS concentration for the simulated period of 1963-2010 was less than 1 percent. This small change was because the effluent concentration was close to that assumed in the modeling for the inflows into the Brady Lake. With an assumed effluent TDS concentration of 1,000 mg/L, the 12-month pumping scenario was predicted to result in almost an 11 percent increase in the average reservoir TDS, and for the 5-month pumping scenario the increase was just over 5 percent. Because the actual TDS concentrations of tributary inflows were not well defined and the TDS concentration of the Brady WWTF effluent was unknown, these results must be viewed within the limitation imposed by the assumed input to the WRAP model. However, the results do indicate that depending upon the actual concentration of the WWTF effluent, there could be negative impacts to the already elevated TDS concentrations often occurring within Lake Brady.



a) Comparison of baseline & January – December effluent pumping scenario



b) Comparison of baseline & November – March effluent pumping scenario

Figure 47 **Comparison of Brady Lake storage volume for baseline and two effluent pumping scenarios for the period of 1963-2010**

Table 31 Comparison of Brady Lake storage volume for baseline conditions and the two scenarios considering pumping of effluent from the City of Brady WWTF for the simulated period of 1963-2010

Simulated Condition	Pumping Period	Total Inflow (ac-ft)	Total Net Evap. (ac-ft)	Average Reservoir Storage Volume (ac-ft)	Percent Change in Storage (%)
Baseline	–	345,235	204,379	18,672	–
Effluent Pumped	Jan.-Dec.	362,515	212,296	19,612	5.0%
Effluent Pumped	Nov.-Mar.	352,405	207,768	19,064	2.1%

Table 32 Comparison of Brady Lake TDS concentration for baseline conditions and the two scenarios considering pumping of effluent from the City of Brady WWTF for the period of 1963-2010

Simulated Condition	Pumping Period	WWTF Effluent TDS Concentration (mg/L)	Average Brady Lake TDS Concentration (mg/L)	Percent Change in TDS (%)
Baseline	–	345,235	865	–
Effluent Pumped	Jan.-Dec.	500	869	0.4%
Effluent Pumped	Jan.-Dec.	1,000	958	10.7%
Effluent Pumped	Nov.-Mar.	500	868	0.3%
Effluent Pumped	Nov.-Mar.	1,000	909	5.1%

12.0 EDUCATION AND OUTREACH DURING WPP DEVELOPMENT

The Education and Outreach activities of the Brady Creek Watershed Protection Plan were primarily conducted by the Upper Colorado River Authority. The goal of the Education and Outreach Program was to establish a community based component of the WPP to develop a balanced and diversified stakeholder group, enhance public understanding of the project and encourage early and continued public participation in selecting, designing and implementing appropriate NPS management measures

12.1 EDUCATION AND OUTREACH EFFORTS

In support of the watershed action planning (WAP) efforts conducted pursuant to the completion of the Brady Creek WPP, the UCRA contacted steering committee members from previous Brady Creek NPS related projects to form the nucleus of the WPP Steering Committee and stakeholder group. Additional members were recruited by UCRA and existing committee members through presentations at meetings of other groups and associations, and through individual solicitation. Early in the process a Public Participation Plan (PPP) was developed and approved by TCEQ that guided the Steering Committee's actions. Because of the large areal extent of the watershed, the location of Committee meetings was alternated between the City of Brady and the City of Melvin. This diminished the travel burden for stakeholder group members.

To engage and inform stakeholders to support and participate in the development of the WPP, an assortment of outreach and education strategies was utilized. The resources and efforts used in implementing the outreach and education strategies are presented in the remainder of this section of the WPP.

12.1.1 Project Websites

Project information is included on the UCRA and TCEQ websites. The URLs for these sites are as follows: the UCRA website address is http://www.ucratx.org/brady.html and the TCEQ website address is http://www.tceq.texas.gov/waterquality/nonpoint-source/projects/brady-creek-watershed-protection-plan. Information provided on these websites includes links to a project Fact Sheet, the Monitoring and Modeling QAPPs, updates to the QAPPS, the PPP, the Brady Watershed Characterization Plan, Steering Committee meeting minutes, presentations presented at Committee meetings, copies of newspaper articles, and a link for the public to request additional related archived information.

12.1.2 The Brady Creek WPP Fact Sheet

The Brady Creek WPP Fact Sheet was developed to provide a succinct synopsis of the project. It provides background geographical information, acknowledges the dissolved oxygen impairment, names other stakeholder concerns, presents the projects goals, delineates funding for the project and lists project partners. The Fact sheet was updated semi-annually, and contingent upon future funding, updates to the Fact Sheet will be made as conditions warrant. It was sent out to Steering Committee members and stakeholders and is available at the TCEQ and UCRA websites.

12.1.3 Media

Prior to Steering Committee meetings, the Brady Standard Herald (Brady's local newspaper) and KNEL AM and FM (Brady's radio station) were presented with news releases advertising the date, time, and purpose of the meetings. The releases also invited interested citizens to attend and encouraged their participation.

A series of news articles was published in the Brady Standard Herald regarding project status, and concerns and issues discussed at various Committee meetings. Copies of these articles are available at the UCRA website address: http://www.ucratx.org/media2013.pdf.

12.1.4 Targeted Outreach and Education

After visiting with the Brady Elementary School principal and teachers, a curriculum and supporting materials of the Texas River Program, published by the Texas Water Development Board (TWDB), was purchased and distributed to 4th grade teachers. The curriculum materials included teacher materials, CDs and class workbooks. UCRA's Education Director provided teacher education and support, and communicated with the principal and teachers regarding potential future programs. Other UCRA materials on NPS pollution were also distributed to the teachers.

12.1.5 Other Outreach

Periodically, stakeholders were emailed information regarding pertinent area events. A project status presentation was given to the Brady City Council. Council members were invited to participate in an Urban Brady Advisory Group, an invitation that was accepted by some members.

13.0 MANAGEMENT MEASURES

Management measures can be defined as activities that are implemented within the watershed to support or achieve the goals of the WPP. Both structural and non-structural activities can be utilized to achieve goals. As part of the WPP process for submission of plans to the EPA, an evaluation of all identified potentially achievable management measures is necessary to allow discernment of the most practicable site specific measures for the site-specific watershed area.

The Brady Creek stakeholder group evaluated many possible management measures and, based upon that evaluation, selected and prioritized BMPs with the highest likelihood of achieving the stakeholder driven WPP goals. The final BMP selections include both structural and nonstructural BMPs developed to enhance DO levels throughout the Urban Brady Creek reach. Structural BMPs include the installation and operation of a system to pump treated wastewater effluent from Brady's WWTF to the upper end of Urban Brady Creek in Richards Park to enhance streamflow, the installation and maintenance of hydrodynamic vortex separators to reduce the levels of TSS, TN, TP and BOD in stormwater entering Urban Brady Creek from 9 subbasin outlets, and the implementation of an education and outreach program based on USEPA's "Getting in Step" program.

Other stakeholder concerns for which possible management measures were evaluated included the causes of increasing TDS (salinity) in Brady Lake, the effect on flows into Brady Lake from brush encroachment in the upper watershed, and the functionality and maintenance of PL-566 dams in the upper basin.

The functionality and maintenance of PL-566 dams and reservoirs and the potential water yield benefits to be gained from brush control in the upper basin were evaluated through application of the SWAT model. Model results indicated that the presence of PL-566 reservoirs prevent significant amounts of TSS, TN, and TP from entering Brady Lake (see Section 10 herein and Chapter 6 in the Modeling Study, Appendix B). No management measures are recommended by the stakeholders regarding the PL-566 dams and reservoirs.

The SWAT model was applied to estimate changes in annual average water yields based on an optimistic assumption of 100% removal of brush from the upper basin. Two scenarios were modeled. In the best case scenario, the model predicted a maximum increase in surface flow to Brady Lake of 14% (see Section 10 herein and Chapter 6 in the Modeling Study, Appendix B). However, given the ranking guidelines that the TSSWCB uses in selecting projects for cost matching water enhancement projects and the very high likelihood of significantly less than 100% participation of landowners in the upper basin, the stakeholders did not consider brush control as a practicable management measure.

Using SWAT and WRAP the effect that evaporative losses has on salinity in Brady Lake was evaluated. TDS was used as the measure of salinity. The modeled results clearly indicate that the major component of the increasing TDS trends in Brady Lake is attributable to evaporation losses (See Chapter 7 in the Modeling Study, Appendix B).

The effects on TDS concentration and on reservoir storage volumes resulting from the potential pumping of treated WWTF effluent pumping into Brady Lake were also evaluated. The results indicated that some benefit to reservoir storage would be realized from pumping treated effluent into Brady Lake. However, this benefit would be offset by the result that water quality would be negatively impacted through increased TDS concentrations. The stakeholders did not recommend pumping WWTF effluent into Brady Lake.

13.1 WWTF EFFLUENT PUMPING TO ENHANCE BRADY CREEK FLOW

The single most important management measure identified in the Brady Creek WPP and key component to the remediation of depressed DO through the Urban Brady Creek reach, is a structural BMP comprised of the seasonal pumping (April through October) of effluent to Richards Park to enhance streamflow. This BMP consists of the installation of a pumping system and pipeline from the City of Brady's WWTF to a point on the eastside Richards Park pool. This pool is located immediately downstream and east of the concrete dam located near the westernmost limit of the park. Figure 48 is an aerial view with a schematic drawing of a proposed recirculation pipeline route (dashed line) taken from the 2004 Brady Creek Urban Runoff/NPS Master Plan. It illustrates a substantial portion of the pipeline route that the herein recommended WWTF effluent pumping BMP would follow. The Master Plan recommended the re-circulation of water from the Elm Street reservoir to the Richards Park westside pool. The WTTF effluent pumping BMP would pump treated effluent from the WWTF located approximately 1 mile downstream of the Elm Street reservoir rather than re-circulating water from the Elm Street reservoir. It would instead discharge treated effluent through a diffuser located downstream of the dam that forms the Richards Park westside pool thereby enhancing streamflow through Urban Brady Creek. The pipeline route from the WWTF would parallel Brady Creek to the Elm Street reservoir thence along the route illustrated in Figure 48.

Figure 48 **Proposed recirculation pipeline route taken from 2004 Brady Creek Master Plan (Urban Runoff/NPS Abatement Project)**

For this BMP to be successful, cooperation of the City of Brady is essential. In the most recent Stakeholder Committee meeting, the Interim City Manager of Brady agreed in principle to this BMP as did downstream stakeholders. However at that time, the City was in the beginning phase of the planning process for building a new wastewater treatment system to replace the one they currently operate. The City is also considering a wastewater collection system for the residents at Brady Lake so that their waste streams can be treated by a WWTF instead of the numerous individually owned onsite sewage systems that all houses at the lake currently utilize. The City had commissioned Sealy Engineering, Inc. to develop a feasibility study to compare the costs of several alternatives for the treatment of Brady's wastewater and the disposal of the treated effluent. The seven alternatives considered included the following:

1. Two plants with effluent discharge into Brady Creek at existing outfall
2. One plant at existing site with discharge into Brady Creek at existing outfall
3. Two plants with effluent discharge into the lake and Brady Creek at Richards Park
4. One plant at existing site with discharge into Brady Creek at Richards Park
5. Two plants with effluent discharge into Brady Creek at Richards Park
6. Two plants with effluent discharge into the lake
7. One plant at existing site with effluent discharge into lake

At the time of the last stakeholder meeting the feasibility study was not finished. However, since that meeting, the city received the completed feasibility study. The costs presented in that study for alternative 4, the most economically feasible of the three that would discharge into Brady Creek at the park, is shown in Table 33.

Table 33 Effluent pumping to enhance Urban Brady Creek streamflow, Estimated construction costs

Item	Units	Unit Cost	Total Cost
Pipeline Installation (18"PVC)	12,350 feet	$55/ft.	$69,250
Pump Station			105,750
Total Cost			$785,000
Annual O&M Est. Cost			$11,667

Estimated costs derived from Sealy Engineering WWTF Feasibility Study for City of Brady

Since that stakeholder meeting, the City has hired a City Manager, a new Utilities Director, and a different consulting engineering firm. The new engineering firm is currently in the design phase of a WWTF to eventually be constructed at the existing WWTF site. The discharge segment of the new facility could easily be designed and/or retrofitted to pump treated effluent to Richards Park.

As an added incentive to the City of Brady, it has been determined that a portion of the costs associated with construction of the infrastructure necessary to pump effluent to Richards Park would qualify as "green infrastructure," and as such, be eligible for partial loan forgiveness under TWDB Rules; plus there are certain other inducements and advantages to the city to select the effluent pumping BMP, i.e. the delisting of the Urban Brady Creek impairment and the aesthetic improvements to Urban Brady Creek.. However, it is uncertain what WWTF design and what discharge point(s) the City Council will ultimately choose. The UCRA continues to communicate with City of Brady personnel and their engineers to promote selection of the effluent pumping BMP proposed in the WPP.

13.2 INSTALLATION OF HYDRODYNAMIC VORTEX SEPARATORS

Based on available space limitations at subbasin outlets to Brady Creek that precluded the installation of traditional BMPs such as wet or dry ponds, the use of hydrodynamic vortex separators was chosen as a management measure to reduce TSS, TN,TP and BOD loadings by the amounts predicted by the SWMM model. Dissolved Oxygen exceedance duration curves developed from QUA2K model results indicate that full implementation of this BMP coupled with the enhanced streamflow from the effluent pumping BMP provides an excellent chance of attaining DO stream standards 100% of the time. The sizing and number of hydrodynamic vortex separators was determined on a goal of removing on average about 50% of the TSS and BOD loadings.

Table 34 presents the estimated costs for installation of BMPs in each of nine sub-basins. The sub-basins are scheduled for construction based on rank, i.e. sub-basins are scheduled in descending order, from the sub-basin with the largest anticipated positive impact to DO to the sub-basin with the smallest anticipated impact to DO. Maintenance costs are relatively inexpensive and not included in the table. Maintenance consists of removing floatables from the vortex separator, typically after multiple storm events, and deploying a vacuum truck to clean out the material that settles in the bottom of the separator as needed. Although dependant on the frequency of storm events and the amount of solids deposited in the separators, vacuuming of the separators on an annual or biannual basis is anticipated to provide sufficient maintenance. A reasonable cost estimate to maintain each installed unit is $500/year and with 19 total units installed the annual maintenance cost after installation of all units is estimated to be $9,500.

An explanation of how the hydrodynamic vortex separators function is included in Section 9, herein.

Table 34 Hydrodynamic Vortex Separator treatment system estimated installation costs

Sub Basin ID	Vortex Separator Size	Unit Cost	No. of Units	Total Purchase Cost	Design Eng. Cost	BMP Install Cost	Project Mgnt Cost	BMP Total Cost
F	12'	$50,500	6	$303,000	$20,000	$120,000	$50,000	$493,000
D	12'	$50,500	6	$303,000	$20,000	$120,000	$50,000	$493,000
I	12'	$50,500	1	$50,500	$5,000	$20,000	$8,000	$83,500
E	10'	$41,150	1	$41,150	$5,000	$20,000	$7,000	$73,150
C	9'	$32,900	1	$32,900	$5,000	$20,000	$6,000	$63,900
G	9'	$32,900	1	$32,900	$5,000	$20,000	$6,000	$63,900
KS	9'	$32,900	1	$32,900	$5,000	$20,000	$6,000	$63,900
H	9'	$32,900	1	$32,900	$5,000	$20,000	$6,000	$63,900
KN	9'	$32,900	1	$32,900	$5,000	$20,000	$6,000	$63,900
Total Cost		$357,150	19	$862,150	$75,000	$380,000	$124,500	$1,462,150

13.3 EDUCATION AND OUTREACH PLAN FOR WPP IMPLEMENTATION

The Brady Creek Watershed Protection Plan Steering Committee and Stakeholder Group has used the framework of the USEPA “Getting In Step” program as a guideline to develop the education and outreach module for the City of Brady Watershed Protection Plan (Brady WPP). The program desires to develop a strategy that will encourage local stewardship and foster public awareness by increased participation in NPS both non-structural and structural abatement components. The program steps are as follows:

1) Identify the driving force, set goals and objectives
2) Recognize target audience
3) Create the message
4) Package the message
5) Distribute the message
6) Evaluate the plan

13.3.1 Driving Force, Goals and Objectives:

The driving force for the development of the Brady WPP Education and Outreach campaign is that water quality in Brady Creek, through the City of Brady, has continued to degrade since the construction of Brady Lake. Furthermore, Brady Creek was identified as impaired on the Texas 303(d) list in 2004 for not supporting its designated aquatic life use due to depressed DO.

The program goal is to increase awareness within the community in regard to the current conditions of the watershed by providing residents with information and encouraging the implementation of best management practices which could result in the maintenance and restoration of water quality conditions consistent with the State of Texas Surface Water Quality Standards for the designated uses of Brady Creek.

The objectives include the following:

- Continue to increase public awareness of the water quality issues in Brady Creek through local media, printed materials and community events
- Solicit the continued support of local government officials
- Maintain relationships and partnerships with City personnel to support structural BMPs
- Provide additional training to educate city staff in general stormwater pollution prevention practices
- Identify and pursue water quality education and outreach program funding
- Make additional educational programming available within the school system and to local citizens to cultivate stewardship within the community

13.3.2 Recognize Target Audience:

Community action can influence the long term water quality of the creek. A variety of people will be targeted during the program to reach as many of the citizens of Brady and the outlying areas as possible. Many local civic leaders, local business owners and members of the community have already been involved in the development of this WPP. Their continued involvement will be crucial in looking ahead to identify and educate other potential audiences.

Agricultural producers/small acreage landowners
- Ranchers farmers
- Wildlife managers
- Local agricultural agencies
- Ecotourism
- Aquatic complex
- Boating
- Camping
- Fishing
- Hunting
- Annual World Championship Goat Cook-Off
- Golfing
- Youth & Educational Outlets
- Schools

- Local educational organizations
- Gardeners & Homeowners
- Greenspace Management
- Landscapers
- Golf course managers
- Parks and recreation staff
- Sportsmen
- Influential People And Organizations
- Elected officials
- Civic organizations
- Local media
- City managers
- Business, community leaders
- Realtors
- Builders
- Brady Chamber of Commerce

13.3.3 Create the Message:

The various messages will address the overall education and outreach objectives. The message emphasizes the value of the natural resources associated with the city of Brady, as well as the problems and measures that can be taken to achieve positive outcomes. Materials will be developed to be consistent with the Brady WPP priorities with educational activities targeted to be the most effective.

Messages defining the value of the natural resources include:

- Area property values can be preserved or increased by having attractive creeks and lakes
- Brady Lake is a valuable water supply for local residents
- Depressed property value and sales tax revenue loss from decreased ecotourism could impact availability of county services or require increased taxation to maintain service
- Implementing low impact development practices could improve local beautification, scenic value and regional quality of life in the region

Messages defining the problems include:

- What is the Brady Creek watershed?
- Define the current water quality situation in Brady Lake/Creek
- Define the depressed do concerns for Urban Brady Creek
- Define the impairments that impact the current watershed

Messages defining the recommended solutions include:

- Restore DO to acceptable levels by relocation of the City of Brady’s treated wastewater effluent discharge point to the Richard’s Park eastside pool
- Restore the DO to acceptable levels by pumping WWTF effluent into Richards Park eastside pool during the months of April through October

- Reduce TSS, BOD, and nutrients by 50% through the installation of vortex separators at each of 9 subbasins
- Improve agricultural management designed to diminish pollutants
- Improve stormwater management designed to diminish pollutants from urban areas flowing in the lake and creek.
- Improve wildlife and pet waste management designed to decrease fecal contamination of the watershed

Messages defining what individuals can do to help include:

- Find out where you live in relation to the Brady Creek watershed
- Become familiar with the Brady Creek watershed
- Ask your local elected officials to address pollution issues in your community
- Ask your local elected officials about recycling options
- Support local efforts to replace outdated treatment facilities and infrastructure
- Volunteer for community environmental projects, i.e. Local river cleanups and habitat restoration
- Adopt zero tolerance towards littering
- Consider installing rainwater harvesting systems at your home and/or business
- Learn proper mowing and herbicide application techniques at your home or place of business
- Utilize proper livestock, pet and wildlife management techniques

13.3.4 Package and Distribute

Seven strategies (S) will be utilized to execute the Brady Creek Watershed Education and Outreach (E/O) Plan:

S#1 Create and establish a brand

S#2 Convey basic facts about the Brady Creek watershed

- Get basic facts to target audience
- Create engaging literature to distribute that may include photos, mapping, FAQ's, factual info and simple graphics
- Develop presentations for target audience

S#3 Increase awareness of community involvement in the Brady Creek WPP

- Generate awareness through local tv, newspaper, billboards and other appropriate targeted advertising
- Seek grant funding and/or local match support for advertising
- Find opportunities for PSAs and other free advertising
- Work within the community to explore acquisition of curb and gutter signage to increase awareness linking stormwater flows and pollution
- Investigate both direct and indirect educational methods to reach as many citizens as possible through:
    - Presentation at local meetings

- Booths during community wide events
- Host meetings, workshop, conferences
- Direct post mail
- Emails
- Site visits to local property and tours of BMP sites
- Promotional or specialty items
- Media articles
- PSAs on radio or tv
- Utility bill inserts
- Displays at local business frequented by the target audience

S#4 Develop partnerships to distribute message

- Develop partnerships with local business, community based organizations and non-governmental organizations (NGOs) who support environmental education and conservation programs for message distribution which could include but is not limited to:
  - Texas Farm Bureau
  - Local Soil & Water Conservation District
  - NRCS District Office
  - Texas Department Of Agriculture
  - Texas County Ag Agents Association
  - Texas Parks And Wildlife
  - Lower Colorado River Authority
  - Texas AgriLife Extension Service
  - Texas Chapter Of American Fisheries
  - Chamber Of Commerce
  - Local Marina
  - Brady ISD
  - 4-H
  - FFA
  - Girl Scouts
  - Boy Scouts
  - Master Gardeners
  - Homeowners Association
  - Keep Texas Beautiful
  - Local Landscapers
  - City Parks And Recreation Staff
  - Elected Officials
  - Civic Organizations
  - Local Media
  - City Managers
  - Business & Community Leaders
  - Water Supply Corporations
  - Clergy
  - Realtors

- Develop the outreach campaign targeting local business and community based organizations to:
  - Inform them of the Brady Creek Watershed Protection Plan
  - Inform them how water quality problems associated with Brady Creek could impact them
  - Give them specific opportunity to aid the outreach campaign, both personally and professionally, stressing that their venue would be a point of distribution for information about the Brady Creek WPP

S#5 Create smaller campaigns for specific target audiences

Target Audience A: Agricultural producers/small acreage landowners

- Partner to work with organizations that provide technical assistance and funding for the implementation of conservation practices
- Utilize and/or construct BMPs as a learning tool
- Utilize promotional materials, presentations and other informational tools to educate producers on things such as agricultural BMPs, and their cost and benefits, stocking rates and overgrazing and runoff management
- Utilize resources such as Texas Agrilife Extension Service events and media, NRCS/SWCD news outlets, and Ranch & Rural magazine

Target Audience B: Ecotourism

- Compile and keep a current list of ecotourism vendors.
- Host an informational luncheon for vendors with an invitation to participate in water quality improvement efforts to ensure the future of their livelihoods.
- Include vendors in an email listserve to keep them apprised of improvement efforts in Brady.

Target Audience C: Youth and educational outlets

- Identify all after school programming
- Learning centers or day care centers
- Elementary and secondary schools
- Work with local organizations to create a youth based learning curriculum for the Brady Creek watershed
- Use schools as a distribution point for E & O materials, create NPS literature specific to the problems in Brady Lake/Creek
- Reach out to the science teachers to request presence in family nights and science fairs

Target Audience D: Gardeners and homeowners

- Work with various local groups to promote environmentally friendly landscaping for neighborhoods and businesses
- Focus printed literature and presentations in efforts on priority topics i.e. Rainwater harvesting, stormwater management, pet waste management, urban landscape management, onsite wastewater treatment system, gray water management, grass clipping/leaf disposal

- Utilize media in utility billings, tax bills, water supply corporation literature and master gardener programming

Target Audience E: Greenspace management

- Develop BMP demonstration projects for a visual teaching tool to show the effectiveness of reducing runoff and pollution transport
- Develop a list of stormwater control and green infrastructure measures that developers can use and implement in designing new neighborhoods or public areas

Target Audience F: Sportsmen

- Distribute literature at local fishing support business such as bait stores, marinas, sporting goods stores, fishing guide business etc.
- Include specific tasks that a fisherman might employ to improve water quality in Brady Lake/Creek
- Organize fishermen for clean-up days

Target Audience G: Influential people and organizations

- Seek media contact through local newspaper, radio station, tv news spots. PSA opportunity, utility bill inserts or direct message printing, social media and other printed materials
- Seek opportunities to present and distribute educational literature at regularly scheduled civic group meetings, local community meetings and any other event where these people or groups are present
- Participate in community wide events such as the annual World Championship Goat Cook-Off.

S#6 Collaborate with governmental agencies offering environmental E & O. List of potential groups include:

- United States Environmental Protection Agency
- USDA-NRCS
- TCEQ
- LCRA Clean Rivers Program
- Texas State Soil & Water Conservation Board
- Texas Stream Team
- Texas AgriLife Research
- Texas Water Development Board (Water Smart Campaign)
- Texas Parks & Wildlife

S#7 On-going evaluation of the plan

The effectiveness of education and outreach to the community and within the city infrastructure will be gauged throughout the program. Evaluation tools will be utilized before and after select events to assess the cogency of tools, outreach and presentations in convincing participants to make permanent changes that will offer benefit the watershed. A survey will be circulated annually to the Brady Stakeholder Group to appraise their satisfaction with the campaign and seek input for improvements, where needed.

A listserve of attendees will be created after select events for survey to see if lifestyle modifications or changes to city practices were made as a result of the information provided during the event. The E/O program will be evaluated continually with suggestions from stakeholders and participants and incorporated to make the campaign community driven and effective.

In addition to the plan outlined above, components of the education and outreach program that was conducted during development of this WPP will be continued including the maintenance of a Fact Sheet and a website presence.

Table 35 presents the anticipated costs for the first three years of the education and outreach program.

Table 35 Education and Outreach estimated costs

Item	Year 1	Year 2	Year 3	Total Cost
Program Management and Admin.	$45,000	$47,000	$49,000	$141,000
Travel Expenses	$ 2,000	$ 2,050	$ 2,100	$....6,150
Supplies	$ 2,000	$ 2,000	$ 2,000	$....6,000
Other - Media	$ 5,000	$ 5,000	$ 5,000	$ 15,000
Total Estimated Program Costs	$54,000	$56,050	$85,100	$168,150

14.0 MEASURABLE MILESTONES

Due to the dynamic nature of watersheds and the countless variables governing landscape processes across scales of time and space, some uncertainty is to be expected when a Watershed Protection Plan is developed and implemented. As the recommended restoration measures of the Brady Creek Protection Watershed Protection Plan are put into action, it will be necessary to track the water quality response over time and make any needed adjustments to the implementation strategy. As efforts continue, incorporation of new data will improve the understanding of watershed conditions and will drive a more efficient implementation process (Lake Granbury WPP, 2010 and Plum Creek WPP, 2008).

By monitoring water quality trends, specifically anticipated improvements in dissolved oxygen, the stakeholders will be able to evaluate the efficacy of the recommended strategies developed in the WPP. By tracking these data, stakeholders can assess the level of success in meeting the water quality goals of the WPP and make adjustments or alterations as needed. This adaptive approach will collect monitoring data and analyze it for trends and improvements in DO throughout the project's proposed 12 year implementation period. It is recognized that while the monitored water quality improvements may not precisely follow the model-based projections, they will nevertheless serve as a tool to facilitate stakeholder evaluation and decision-making efforts. As the 12 year implementation schedule of BMPs is implemented and the full attainment of pollutant load reduction targets is met, it is anticipated that dissolved oxygen levels in Urban Brady Creek will be fully supportive of its presumed aquatic life use criteria by year twelve.

14.1 STRUCTURAL BMP TARGET WATER QUALITY AND EFFECTIVENESS MONITORING MILESTONES

14.1.1 Hydrodynamic Vortex Separator stormwater treatment systems

Application of the SWMM model predicted annual average percent removal of TSS and BOD at 48% and TN and TP at 24%. The QUAL2K model results predict that this improvement in urban runoff water quality coupled with streamflow enhancements provided by the effluent pumping BMP can achieve DO aquatic life use standards. To accomplish this 50% reduction, the WPP calls for varying numbers and sizes of vortex separators to be installed in each of nine contributing sub-basins. The numbers and sizes of vortex separators needed in each contributing sub-basin was determined through use of published removal efficiencies of Aqua-Swirl hydrodynamic vortex separators and the loadings contributed by each sub-basin. The final configuration of numbers and sizes of Aqua-Swirl units needed in each sub-basin was based on achieving the 50% reduction in loadings.

To achieve the approximately 50% total loading reduction, the BMPs were designed specifically for each sub-basin's loading contribution, which resulted in different annual average percent removal values for each sub-basin (Table 15). In Table 15 the annual average percent removal values are given for each of 4 water quality parameters used by SWMM in simulations. The annual percentage improvement targets were calculated by using the model-predicted annual average pollutant loadings in pounds for each sub-basin (Table 14) multiplied by the model-predicted annual average percent removal (Table 15) of each of the four water quality parameters (Tables

36, 37, 38, and 39). The predicted total pounds of pollutant loadings removed by the BMPs in each sub-basin was divided by the total pounds of pollutant loadings removed by the BMPS of all sub-basins to determine the percentage of the total pollutants removed by BMPs located at each of the subbasins.

Once continuous streamflow has been established by the pumping of WTTF effluent, it is assumed that incremental improvements in DO will correspond incrementally and in a relative fashion to reductions in pollutant load contributions. While it is a certainty that there is not a direct 1-1 direct relationship in the reductions of pollutant constituents and improvement in DO, it is however, considered a reasonable assumption that larger reductions in storm water pollutant loads should result in larger improvements or at least less negative effects to DO from urban runoff. Based on this assumption, Tables 36 through 49 below can be used as a prioritization and ranking tool for the scheduling of BMP construction.

Table 36 Model predicted stormwater TSS loadings removal to meet management measure requirements in lbs and as percentage of total loadings removed

Sub Basin ID	Ann Avg % TSS Reduction	lbs TSS Baseline Condition	Ann Avg lbs TSS Reduction	Sub Basin Rank	Annual TSS Reduction Percentage
C	53%	8905	4719.65	5	7.08%
D	44%	27771	12219.24	2	18.32%
E	56%	9088	5089.28	4	7.63%
F	40%	62838	25135.2	1	37.68%
G	50%	6629	3314.5	6	4.97%
H	45%	6613	2975.85	8	4.46%
I	44%	16600	7304	3	10.95%
KN	52%	5524	2872.48	9	4.31%
KS	50%	6147	3073.5	7	4.61%

Table 37 Model predicted stormwater TP loadings removal to meet management measure requirements in lbs and as percentage of total loadings removed

Sub Basin ID	Ann Avg % TP Reduction	lbs TP Baseline Condition	Ann Avg lbs TP Reduction	Sub Basin Rank	Annual TP Reduction Percentage
C	27%	53	14.31	5	7.30%
D	21%	165	34.65	2	17.67%
E	28%	54	15.12	4	7.71%
F	20%	373	74.6	1	38.03%
G	25%	39	9.75	6	4.97%
H	22%	39	8.58	8	4.37%
I	22%	98	21.56	3	10.99%
KN	26%	33	8.58	8	4.37%
KS	25%	36	9	7	4.59%

Table 38 Model predicted stormwater TN loadings removal to meet management measure requirements in lbs and as percentage of total loadings removed

Sub Basin ID	Ann Avg % TN Reduction	lbs TN Baseline Condition	Ann Avg lbs TN Reduction	Sub Basin Rank	Annual TN Reduction Percentage
C	27%	297	80.19	5	7.27%
D	21%	925	194.25	2	17.62%
E	28%	303	84.84	4	7.70%
F	20%	2093	418.6	1	37.98%
G	25%	221	55.25	6	5.01%
H	22%	220	48.4	8	4.39%
I	22%	553	121.66	3	11.04%
KN	26%	184	47.84	9	4.34%
KS	25%	205	51.25	7	4.65%

Table 39 Model predicted stormwater BOD loadings removal to meet management measure requirements in lbs and as percentage of total loadings removed

Sub Basin ID	Ann Avg % BOD Reduction	lbs BOD Baseline Condition	Ann Avg lbs BOD Reduction	Sub Basin Rank	Annual BOD Reduction Percentage
C	53%	679	359.87	5	7.09%
D	44%	2118	931.92	2	18.36%
E	56%	670	375.2	4	7.39%
F	40%	4793	1917.2	1	37.78%
G	50%	506	253	6	4.99%
H	45%	504	226.8	8	4.47%
I	44%	1266	557.04	3	10.98%
KN	52%	421	218.92	9	4.31%
KS	50%	469	234.5	7	4.62%

Table 40 provides a structural BMP construction schedule and the expected range of cumulative loadings reduction targets on a percentage basis for the vortex separators throughout the 10 year construction schedule. It is recognized that the scheduled order for the installation of vortex separators in each sub-basin is interchangeable and may change during implementation due to unforeseen factors. If this occurs, Table 40 will be amended to reflect the changes in scheduling. Installation of vortex separators is projected to begin in year four after the initiation of effluent pumping. However, the project will be adaptively managed and the installation of vortex separators might begin before the pumping of effluent should the City of Brady firmly commit to the effluent pumping BMP at an earlier date, but delay its construction. The vortex separator systems can be installed at any time once the City commitment is acquired.

The expected cumulative loading reduction target range consists of the sub-basin and parameter specific, smallest to largest annual target percentage improvement of the 4 water quality parameters in Tables 36-39. For example, in construction year 4, the BMP in subbasin F has been completed and the pollutant loading reduction as a percentage of the baseline value is expected to improve by an amount corresponding to the percentage of the total approximate 50% pollutant loads to be removed to achieve the water quality goal. The low end of the percentage target range of the 4 parameters is taken from the expected annual target percent reduction of TSS, which is 37.68% and the high end of the range is taken from the annual target percent improvement of TP, which is 38.03%. The annual target percent improvement values of TN (37.98%) and BOD (37.78%) fall in between the lower and upper limits of the range.

Subsequent year's ranges are cumulatively added to previous year's ranges to arrive at the expected cumulative loading reduction percentage target ranges for the project as a whole. These improvements are based on percentage improvement of stormwater (urban runoff) quality between untreated stormwater entering the hydrodynamic vortex separators and the treated stormwater exiting them, as described below.

Table 40 Structural BMP construction schedule, expected cumulative loading reduction target range and expected DO improvement, (in percentage points from baseline)

BMP Construction Year	BMP Construction Schedule	Sub-Basins Contributing to Cumulative Loading Reduction	Expected Cumulative Loading Reduction Percentage Target Range (from Baseline)		
1	No Construction				
2	Effluent Pipeline				
3	Start Eff. Pumping				
4	F	F	37.68	to	38.03
5	D	F	37.68	to	38.03
6		F,D	55.30	to	56.39
7	I,E	F,D	55.30	to	56.39
8		F,D,I,E	73.28	to	75.14
9	C,G	F,D,I,E	73.28	to	75.14
10		F,D,I,E,C,G	85.33	to	87.45
11	KS,H,KN	F,D,I,E,C,G	85.33	to	87.45
12		F,D,I,E,C,G,KS,H,KN	98.60	to	100.94

Effectiveness monitoring for the vortex separators will consist of the comparison of the analysis of a flow weighted composite sample of inflowing, untreated stormwater to the analysis of a flow weighted composite sample of the treated stormwater exiting the separators. The samples will be analyzed for BOD, TSS, TN and TP. Ideally, two storm events will be sampled at each vortex separator installation, one from an intense rainfall event and one from a minor rainfall event. Flow will be periodically measured during the event from which to develop a hydrograph. A set of five sub-samples should be collected, two from the ascending leg, one at or near the peak flow and two from the descending leg of the storm hydrograph. If practicable, automatic samplers that also measure flow will be utilized. However, it is not always possible to deploy automatic samplers and in this case, best professional judgment will be used to determine the timing of sample collection based on manual measurements of flow. The five sub-samples will be composited on a flow weighted basis prior to analysis. Due to the uncertainty of when suitable rainfall events will occur, a schedule for this BMP effectiveness monitoring cannot be generated. The goal will be to conduct the stormwater sampling events as soon as possible after installation of the separator(s) at each subbasin outlet. It will depend on the source of the funding for these installations, but is considered very likely that a QAPP will have to be developed for the effectiveness sampling related to this BMP. The estimated cost for each sampling event at each of the 19 hydrodynamic vortex separators is $1500, which totals $28,500. However, depending on the design characteristics of the multiple separator installations at subbasins F and D, each separator may not have to be sampled separately, which would reduce the overall cost.

Effectiveness will be determined by the percentage difference of the two samples and whether the result falls within the milestone model predicted target ranges identified in Tables 36-39. The effectiveness monitoring will take place as soon after the installation of each vortex separator facility for each sub-basin as weather conditions allow. The results will be compared to the milestones in Tables 36-39 and allow stakeholders to determine if the expected results are being accomplished. If the analysis indicates that milestones are not being met, adjustments to the design of vortex separator facilities subsequently installed in the other sub-basin watersheds can be made. This may take the form of installing higher capacity separators (larger diameter) or additional separators. Through this adaptive management approach, stakeholders can better ensure that the overall goal of restoring the impaired DO is met.

As previously mentioned, a schedule for effectiveness monitoring cannot be delineated owing to the uncertainties of not only storm frequency, but also precipitation intensity and duration. Thus, incremental milestone completion dates cannot be predicted. However, the incremental milestones will loosely correspond to the construction schedule of vortex separator facilities in each sub-basin.

As soon as the WPP is approved, the monitoring site 17005 in Brady will be re-established through the CRP program. Semi-annual diel monitoring and quarterly routine monitoring will provide an updated a baseline for comparative analysis with anticipated improvements in DO from implementation of the WPP management strategies.

14.1.2 Effluent pumping to enhance Brady Creek streamflow

The DO impairment of Urban Brady Creek results from data obtained in diel (24hr) DO monitoring events and not ambient monitoring. For the segment to meet its presumed aquatic use standard, a 24-hour average DO of at least 4.0 mg/L and a 24-hour minimum DO of at least 3.0 mg/L is required. These criteria are not being supported when 10 percent or more of the data do not attain to each of these criteria (TCEQ, 2010).

Because the TCEQ does not currently accept CWQM data for water quality assessment purposes and the ultimate goal of the structural BMPs recommended in this WPP is the restoration of DO to levels sufficient to remove Brady Creek from the 303d list of impaired water bodies, installation of a Continuous Water Quality Monitoring station is not recommended. The effectiveness monitoring plan for DO includes the reinstatement of site17005 through the CRP Program for quarterly diel monitoring. The data collection will be conducted under the CRP QAPP and SWQM Procedures will be followed. The goal is for the attainment of aquatic life use stream standards as mentioned above. Neither the number of monitoring events nor how long it will take to reach the delisting goal is knowable. Enough data that meets the aquatic life use criteria will need to be collected to meet the statistical assessment needs for delisting of the waterbody. Tracking these data will enable stakeholders to evaluate progress and make adjustments and changes to the WPP if needed. Using the CRP program for this data collection negates the need for additional funding for effectiveness monitoring for this BMP.

14.1.3 Education and Outreach Program

Education efforts for the City of Brady, initiated within the first year, and moving forward into the future, should be open to any community members in the area covered by the WPP. If resources are limited, efforts will be directed towards priority areas.

Years One – Three Milestones

- Work with existing stakeholder group to follow up on prior efforts and use as a decision making soundboard.
- Create promotional materials and package presentations to take to target audiences.
- Implement the small campaign for all target audiences identified in the plan.
- Begin a marketing blitz to educate the community on the benefits of non-structural controls.
- Begin a marketing blitz to educate the community on the benefits of identified structural controls within the city.
- Identify, pursue and secure partnerships for potential funding of structural management measures.
- Identify and pursue funding sources for structural management measures.

Long Term
- Continue education efforts and pursuit of funding until goals are achieved.
- Implement any projects receiving funding

Progress meeting the education and outreach milestones listed above will be reported to stakeholders and partners initially on a quarterly basis then after the 3 year initial implementation period stakeholders will review reporting needs and adjust frequency of reporting if appropriate.

14.2 PROGRAM IMPLEMENTATION

14.2.1 Technical Assistance and Cooperation

Successful implementation of the Brady Creek WPP relies on active engagement of local stakeholders, but also will require support and assistance form a variety of other sources. The required funding, technical expertise, equipment and manpower required for recommended management measures is beyond the capacity of the Brady Creek stakeholders alone. Moreover, because the local stakeholders do not benefit from significant local financial and technical resources or a large base of local institutional support, direct support (including financial support) from entities located outside the watershed will be essential to achieve the water quality goals in the watershed.

Most technical assistance needs will continue to be provided by the Upper Colorado River Authority. UCRA personnel, among other tasks pursuant to successful implementation of the Brady Creek WPP, will continue to serve in a watershed coordination roll overseeing the implementation of this WPP, seeking funding sources and financial assistance for implementation of management measures, writing grant applications, managing projects, coordinating activities and engendering cooperation with local entities, engaging stakeholders, etc.

The City of Brady and its citizens recognize Brady Creek as a valuable natural resource and citizens were a significant partner and contributor to the development of the WPP. Brady hosted several of the stakeholder meetings, provided storage for stormwater sampling equipment and assisted with automatic sampler deployments during storm events. Moreover, the current City Manager has indicated Brady's conceptual agreement with the recommended BMPs and has pledged the City's continued support in the implementation of the WPP. Although no other technical needs have been identified, other potential partners that may contribute to technical needs and cooperate with UCRA in the WPP's implementation include TCEQ, EPA, TWDB, Texas Department of Transportation, Texas Parks and Wildlife, U. S. Fish and Wildlife Service, and the U. S. Geological Survey.

14.2.2 Urban Brady Creek Management Measures Aggregate Funding Needs

The estimated funding needs for this WPP are tabulated in Table 41, below.

Table 41 Aggregated estimated funding needs

Management Measures	Estimated Cost	Potential Funding Source
Effluent Pumping Streamflow Enhancement	$785,000	City of Brady, SRF, UCRA, CRP
Hydrodynamic Vortex Separators	$1,462,150	City of Bready, UCRA, 319h
Education Out Reach Program Implementation	$168,150	City of Brady, UCRA, 319h
Total Aggregated Estimated Costs	$2,415,300	

14.2.3 Sources of Funding

Successful acquisition of funding to support implementation of management measures will be critical for the success of the Brady Creek Watershed Protection Plan. The management measures recommended in the WPP require significant funding for initial construction and implementation. As previously mentioned, the Brady Creek stakeholders do not benefit from significant local financial and technical resources, nor a large base of local institutional support, Because of this, direct support from entities located outside the watershed will be essential to achieve the water quality goals. Discussions with the steering committee and work groups, city officials, agency representatives, and other professionals were used to estimate financial needs. Traditional funding sources will be utilized where available, and creative new approaches to funding will be sought. Some of the key potential funding sources that will be explored include:

Clean Water Act State Revolving Fund

The State Revolving Fund (SRF) administered by the TWDB provides loans at interest rates below the market to entities with the authority to own and operate wastewater treatment facilities. Funds are used in the planning, design, and construction of facilities, collection systems, stormwater pollution control projects, and nonpoint source pollution control projects.

Economically Distressed Area Program (EDAP)

The Economically Distressed Area Program is administered by the TWDB and provides grants, loans, or a combination of financial assistance for wastewater projects in economically distressed areas where present facilities are inadequate to meet residents' minimal needs. While the majority of the watershed does not meet these requirements, small pockets within the area may qualify based on economic requirements of the program. Groups representing these areas may pursue funds to improve wastewater infrastructure.

Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program is administered by the NRCS. This voluntary conservation program promotes agricultural production and environmental quality as compatible national goals. Through cost-sharing, EQIP offers financial and technical assistance to eligible participants for the installation or implementation of structural controls and management practices on eligible agricultural land. This program will be engaged to assist in the implementation of agricultural management measures in the watershed.

Regional Water Supply and Wastewater Facility Planning Program

The TWDB offers grants for assessments to determine the most feasible alternatives to meet regional water supply and wastewater facility needs, estimate costs associated with implementing feasible wastewater facility alternatives, and identify institutional arrangements to provide wastewater services for areas across the state.

Section 106 State Water Pollution Control Grants

Through the Clean Water Act, federal funds are allocated along with matching state funds to support state water quality programs, including water quality assessment and monitoring, water quality planning and standard setting, TMDL development, point source permitting, training, and public information. The goal of these programs is the prevention, reduction, and elimination of water pollution. This source of funding may be sought for portions of the education and outreach BMP.

Section 319(h) Federal Clean Water Act

The USEPA provides funding to states to support projects and activities that meet federal requirements of reducing and eliminating nonpoint source pollution. In Texas, both the TSSWCB and the TCEQ receive 319(h) funds to support nonpoint source projects, with TSSWCB funds going to agricultural and silvicultural issues and TCEQ funds going to urban and other non-agricultural issues. Additional support will be sought from these sources, as appropriate.

Supplemental Environmental Project Program (SEP)

The Supplemental Environmental Projects program administered by the TCEQ aims to direct fines, fees, and penalties for environmental violations toward environmentally beneficial uses. Through this program, a respondent in an enforcement matter can choose to invest penalty dollars in improving the environment, rather than paying into the Texas General Revenue Fund. In addition to other projects, funds may be directed to septic system repair and wildlife habitat improvement opportunities.

Targeted Watersheds Grants Program

The Targeted Watersheds Grants Program is administered by the EPA as a competitive grant program designed to promote community-driven watershed projects. Federal, state, and local programs are brought together to assist in the restoration and preservation of water resources through strategic planning and coordinated project management by drawing in both public and private interests.

Texas Clean Rivers Program (CRP)

The CRP is a statewide water quality monitoring, assessment, and public outreach program funded by state fees. The TCEQ partners with 15 regional river authorities to work toward achieving the goal of improving water quality in river basins across the state. CRP funds are used to promote watershed planning and provide quality-assured water quality data. The Partnership will continue to engage this source to support and enhance surface water quality monitoring in the watershed. support will sought from CRP by requesting the reinstatement of diel monitoring in the urban portion of Brady Creek.

Water Quality Management Plan Program

The WQMP program is administered by the TSSWCB. Also known as the 503 program, the WQMP program is a voluntary mechanism by which site-specific plans are developed and implemented on agricultural and silvicultural lands to prevent or reduce nonpoint source pollution from these operations. Plans include appropriate treatment practices, production practices, management measures, technologies, or combinations thereof. Plans are developed in cooperation with local SWCDs, cover an entire operating unit, and allow financial incentives to augment participation.

EPA Urban Waters Small Grants Program

The goal of the Urban Waters Small Grants Program is to fund research, investigations, experiments, training, surveys, studies, and demonstrations that will advance the restoration of urban waters by improving water quality through activities that also support community revitalization and other local priorities. In 2014 the Environmental Protection Agency selected 37 organizations to receive grants of $40,000 to $60,000 each, totaling approximately $2.1 million to support such projects. The funding is part of EPA's Urban Waters program, which supports communities in their efforts to access, improve, and benefit from their urban waters and the surrounding land.

USDA Water and Environmental Programs

Water and Environmental Programs (WEP) provides loans, grants and loan guarantees for drinking water, sanitary sewer, solid waste and storm drainage facilities in rural areas and cities and towns of 10,000 or less. Public bodies, non-profit organizations and recognized Indian tribes may qualify for assistance. WEP also makes grants to nonprofit organizations to provide technical assistance and training to assist rural communities with their water, wastewater, and solid waste problems.

Texas USDA-Rural Development Community Facilities Loans

Community Programs can guarantee loans to develop essential community facilities in rural areas and towns of up to 20,000 in population. Loans and guarantees are available to public entities such as municipalities, counties, and special-purpose districts, as well as to non-profit corporations and tribal governments. Loan funds may be used to construct, enlarge, or improve community facilities for health care, public safety, and public services. This can include costs to acquire land needed for a facility, pay necessary professional fees, and purchase equipment required for its operation.

TWDB Development Fund

The Development Fund II program, administered by the TWDB, includes state loans (does not receive Federal subsidies) for water supply, water quality enhancement, flood control and municipal solid waste. This Development Fund II serves the purposes previously served by Development Fund (Development Fund I), but separates the State Loan Program from the State Participation Program and the Economically Distressed Areas Program components. The Development Fund II enables the Board to fund multiple eligible components in one loan to borrowers, e.g., if an applicant applies for funding of water and wastewater components, this is done with one loan. Financial assistance for Wastewater (Water Quality Enhancement Purposes) may include acquisitions and improvements or construction of wastewater facilities such as sewer treatment plants and collection systems. Nonpoint Source pollution abatement is also eligible. Development of new municipal solid waste disposal facilities can also be funded. Eligible applicants include political subdivisions, districts, water supply corporations and access is on a first-come, first-serve basis.

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APPENDIX A

Brady Creek Watershed Characterization

APPENDIX B

Brady Creek Watershed Modeling Study

APPENDIX C

Brady Creek Watershed Public Participation Plan